



Tidewater Center

Post Office Box 629 Langley Air Force Base, VA 23665 Tel. Com: (804) 766-1812 Autovon: 574-3745

6 March 1995

A. Gary Price, Head  
Office of External Affairs

Dear Gary Price:

Thank you for reviewing my manuscript, *Human Computers: The Women in Aeronautical Research*. In response to your suggestion, I am donating a copy of the manuscript for your archives in the hope that this unique and valuable information will be available for any future research of the NACA years.

Very truly yours,

Dr. Beverly E. Golemba

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March 21, 1995

Dr. Beverly E. Golemba  
Saint Leo College  
P. O. Box 629  
Langley Air Force Base, VA 23665

Dear Dr. Golemba:

I would like to thank you for allowing us to keep a copy of your manuscript, *Human Computers: The Women in Aeronautical Research*, in our historical archives for future reference. I am sure historians will find the material useful.

Enclosed is a copy of a recent history on our Center. You might find it interesting. Thank you again for allowing us to review your material. I continue to wish you the best as you look for a publisher.

Sincerely,

ORIGINAL SIGNED BY

A. G. Price  
Head, Office of External Affairs

Enclosure

cc (w/o encl):

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446/R. T. Layman

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115/AGPrice:jj 3-22-95 (46124)

HUMAN COMPUTERS:

THE WOMEN IN AERONAUTICAL RESEARCH

Beverly E. Golemba

## NACA/NASA

Since people are more familiar with the term NASA than the term NACA, and NACA the primary focus of this study, the years for these agencies is given here:

National Advisory Committee for Aeronautics (NACA) 1915-1958

National Air and Space Administration (NASA) 1958 to present

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## INTRODUCTION

The attitude toward women in science, although somewhat improved, still treats this as an emerging phenomenon, and while young women are presently being encouraged to go into the sciences, the long history of women in science is unknown to them. The young women of today are not aware of the struggles and successes of early women scientists. As noted by historian Marilyn Bailey Ogilvie (1983, Preface), one of her students, upon not finding any information about women in science, asked if Marie Curie was the only woman in science. Evelyn Fox Keller (1985, p.3) states that because science is considered masculine, there is the false assumption "that a study of gender and science could only be a study of women." Both of these authors expressed the same difficulty I had experienced in finding sources for information when I was writing *Lesser-known Women*(1992). In view of the topic of this book, women as human computers, it is unlikely that most people are aware that it was Ada Lovelace, a woman, who, in 1842, developed the prototype of the present day electronic computer.

While the successess of women in science are little known, the struggles of women in this field are even less likely to be known. For example, I found that among mathematicians,

Marie Agnesi's versed sine curve published in 1748, with the Latin *versiera* wrongly translated into witch, was given the pejorative term, "witch of Agnesi". Sofya Kovalevsky, who developed partial differential equations, is reported to have secretly taught herself mathematics, and Sophie Germain was not awarded a prize for her work in mathematics until 1815 after she had submitted the same work three times. Riger (1992, p. 730), describes this exclusion of women as a "reflection of the desire for domination characteristic of a culture that subordinates women's interests to those of men."

The women in this book recognize that the opportunity to use their mathematical skills other than in teaching came about because of the shortage of male mathematicians during World War II; none felt they would have had this opportunity under peacetime conditions. Their story has not been told before and as happened to other women, males reclaimed the field after the war and the women were forgotten. In Ceruzzi's *Beyond the Limits*(1989), a book about the development of electronic computers, there are no females present in a photograph of early hand calculations and use of calculators (p.32-33). While the women in this study did not make the contributions of the women mathematicians noted above,

aviation and aeronautical research were in their infancy during the time they were at NACA, and they contributed much to the development of this field of science.

With the rapid development and widespread use of electronic computers, there is a tendency to forget that all computations were formerly done by hand; computing a verb, has become computer, a noun. The women in this book had the title Computer because they performed all of the mathematical calculations by hand in the early development of aeronautics and the later development of space research.

I first met a few of the women who had been "human computers" at a seminar given in their honor at NASA-Langley in 1990. It is uncertain who had arranged for this long overdue recognition. While the seminar was not well attended, everyone present seemed captivated by these women and the story of their years as human computers at NACA/NASA. The women, now all in their 70s and 80s and all very poised and charming, gave a brief description of the work they had performed and the type of research in which they had been involved. The local newspaper included a short article and a photograph of some of the women in the

following day's edition; however there was the likelihood these human computers would quickly return to obscurity. Because what they related that day was fascinating, I felt their complete story would be of interest to many. The dual purpose of this book is to tell their story and to show how these women serve as role models for the young women of today, especially those considering careers in science.

It was two years after meeting the human computers before I was free to contact them and arrange for interviews. It is unfortunate that of the several hundred computers that worked at NACA only 13 were found at the time the study was done. Several had died or moved while others were unable to be contacted for inclusion, but the women included in this study are highly representative of these human computers. The 13 women are: Vivian Adair, Rowena Becker, Margaret Block, Marie Burcher, Betty Farmer, Vera Huckel, Mary Jackson, Helen Johnson, Emma Jean Landrum, Kathryn Peddrew, Dorothy Vaughan, Barbara Weigel, and Helen Willey.

Vivian Adair was born in Clinton, South Carolina in 1916, graduated from Brenau College in 1937, and worked at NACA from 1943 to 1973; Rowena Becker (nee Daniel) was born in Henderson, North Carolina in 1921, graduated from Meredith

College in 1942, and worked from 1942 to 1947; Margaret Block (nee Leach) was born in Kinston, North Carolina in 1929, graduated from Meredith College in 1951, and her years at NACA were 1951 to 1956; Marie Burcher (nee Bird Allen) was born in Bland, Virginia in 1921, graduated from Longwood College in 1941, and was at NACA from 1942 to 1949; Betty Farmer (nee Carns) was born in Carlisle, Pennsylvania in 1922, attended Radford State College from 1940 to 1942, and was at NACA from 1958 to 1988; Vera Huckel was born in Philadelphia in 1908, graduated from the University of Pennsylvania in 1929, and worked at NACA from 1939 to 1972; Mary Jackson (nee Winston) was born in Hampton, Virginia in 1921, graduated from Hampton Institute in 1942, and she was at NACA from 1950 to 1985; Helen Johnson was born in Franklin, Virginia in 1906, attended Hollins College from 1924 to 1926 and graduated from the College of William and Mary in 1929, and worked from 1942 to 1976; Emma Jean Landrum was born in Daytona Beach, Florida in 1926, graduated from the University of North Carolina in 1946 (she earned her Master's degree from the College of William and Mary in 1961), and worked at NACA from 1946 to 1978; Kathryn Peddrew was born in Martinsburg, West Virginia in 1922, graduated from Storer College in 1943, and her years at NACA were from 1943 to 1986; Dorothy Vaughan (nee Johnson) was

born in Kansas City in 1910, graduated from Wilburforce University in 1929, and was at NACA for the years 1943 to 1971; Barbara Weigel was born in Princeton, New Jersey in 1921, graduated from New Jersey College for Women in 1944, and was at NACA FROM 1944 to 1980; and Helen Willey (nee Hudson) was born in Kinsale, Virginia in 1911, graduated from Blackston Junior College for Girls (1929) Randolph Macon Woman's College (1931) and Columbia University in 1938. Huckel, Weigel, and Willey had careers at NACA that each spanned more than 30 years.

Four of the aeronautical engineers involved in much of the research included in this study were consulted about the research projects and their impressions of the work done by the human computers. They are: Ralph Bielat, Harvey Hubbard, Domenic Maglieri, and Axel Mattson (see Biographies).

With the exception of Marie Burcher with whom I met at a local Ramada Inn because of the distance involved for both of us, the interviews were conducted in the women's homes. The first human computer interviewed was Margaret Block. She lives in a spacious home with her husband Joe (retired from NACA/NASA), and it was apparent that Joe was very proud of

her. Margaret still keeps in touch with former NACA people, and provided me with the greatest number of photographs of women from the NACA years. I next interviewed Rowena Becker whose

home provides a beautiful view of a well kept garden and huge old trees. Whereas Margaret Block had been open and friendly, Rowena was quiet and modest. Her husband John (a former Division Chief at NACA/NASA) was always present during the interviews, but remained in another part of the house unless called upon for information. Becker, Burcher, and Block are married, Willey, Peddrew, Vaughan, Jackson, and Farmer are now widows, while Huckel, Johnson, Adair, Weigel, and Landrum remained single.

Helen Willey was my greatest source of information; having only retired from NASA in 1973 after 32 years, her memories were more recent and extensive than any of the others. She was able to provide me with artifacts that no longer exist anywhere else. Mary Jackson's home is as busy a place as she is; she is more actively involved in current projects than any of the others. The remaining nine human computers were as enthusiastic and helpful as those mentioned by name.

I found it interesting that none of the 13 computers (including their husbands) or the four engineers interviewed reported any bad events or memories of their years at the Langley facility; I doubt all 19 of them used selective memory. I was fortunate in that the human computers and the engineers were all young when they arrived, established their careers at NACA/NASA, and settled in Hampton and the surrounding area, making contacting and interviewing them much more possible. This is their account of their years as human computers.

Aeronautics was a new field, and everyone working in it was involved in the discovery of aerodynamic principles as well as the research and development of heavier-than-air vehicles. The speed of development of the field was accelerated by the urgent need for aircraft in World War II. Existing aircraft had to be made faster and safer, and new aircraft needed to be developed. This urgency required the building of facilities to do the needed research, the hiring of engineers able to use their skill and training to conduct this new research (there was not yet a college degree in aeronautical engineering at that time), and the hiring of women mathematicians to calculate the research data.



These human computers who studied mathematics in college were unusual for their time. It was not the custom in the 1930s for families to send young women to college, and young women were not thought to be capable of learning higher mathematics. Had it not been for the war, they probably would have either entered or remained in the more customary field for women, teaching.

Because it was pioneer work, the engineers, mechanics, and human computers had to work as a team: the engineers designed the research, the mechanics built the models, and the computers did the computation of the data. Although the development of needed aircraft (aeronautics) took priority, theoretical research into the principles of aerodynamics and designing research facilities to test these principles were also essential.

Development was both rapid and overlapping. New aircraft based on research were designed, theoretical principles were established, and knowledge of faster speeds and higher altitudes which led to the Space Age was developed. In less than 50 years aeronautics had gone from biplanes to space vehicles.

While many of the human computers terminated work once they started families (customary for the times), many remained after the war and some worked into the Space Age. Several of the women became engineers while others took on the challenge of moving into the electronic computer era. Even then it was a challenge because the first electronic computers did not have programs appropriate for aerodynamic research and these women wrote the first programs. Since the pace of research had not lessened once they were on the threshold of space flight, research, principles, and data all had to be developed simultaneously. Again this called for cooperative teamwork.

The women in this study were intelligent, resourceful, and hard working; they continue to this day to retain these characteristics. The most difficult part of the interviews was to get these women to overcome their modesty. While all of them report realizing they were doing pioneer work that was critical, especially during the war years and into the Space Age, all were reluctant to take what they felt was undue credit for their contribution. For example, Harvey Hubbard and Dominic Maglieri, two of the four engineers interviewed, noted that although Vera Huckel played a key role in their research, she was reluctant to have her name included on published reports.

The women all have excellent memory, are factual in their reporting, and are proud of the work they did. The computers and the engineers were given a copy of the section of the manuscript describing the work they did and were asked to review it for errors or changes that were needed in order to ensure greater accuracy.

The engineers held the human computers in the highest esteem. They acknowledge that it was only through the cooperative effort and high level of performance on the part of everyone involved from engineers through technical writers (with the best known of these Pearl Young) that the accomplishments they achieved were possible.

These women remain quite active with only a few of them restricted by health from doing as much as they would like to do. They are active in church work, civic organizations, travel, environmental work, and tutoring students. Because most of them retired several years ago, they report they are no longer as interested in the NASA program as they were while working and for awhile later. They describe their years at NACA and NASA as a stage in their lives which has passed, and they now concentrate on their present and future activities.

The first section describes the arrival of the human computers at NACA, and is followed by the history of NACA (it was not until 1958 that the Agency was renamed NASA). The next section describes the work done by the human computers. This is followed by a description of the recruitment policy, where personnel were housed, and the means for transportation. The fifth section discusses the evidence of sexism during these years. The sixth and seventh sections, covering later years, describes the sonic boom studies and the transition to electronic computers. The individual biographies of the 13 human computers and the four engineers included in this study are given following the Afterword.

## ARRIVAL AT NACA

Arrival at NACA: Vera Huckel arrived in 1939; Helen Willey in 1941; Rowena Becker, Marie Burcher, and Helen Johnson in 1942; Vivian Adair, Kathryn Peddrew, and Dorothy Vaughan in 1943; Barbara Weigel in 1944; Emma Jean Landrum in 1946; Margaret Block and Mary Jackson in 1951; and Betty Farmer in 1958, the year NACA officially became NASA.

Prior to the arrival of the human computers, engineers ran a research project and then performed the laborious job of computing their findings before being able to proceed with the research. Because this was very time consuming and their computations not always error free nor rechecked by someone else, NACA officials decided to hire computers for this phase of the research. On the brink of war and realizing that male computers would be almost impossible to hire, NACA issued bulletins throughout the country advertising these positions. Because of the male shortage and the added attractiveness of paying women less, they rather reluctantly began to hire women as computers. The women in this study note that it seemed that the more physically attractive a woman was, the more likely she was to get hired.

In 1939 Vera Huckel was the first to arrive. While most of the computers applied directly to NACA for the position, Huckel was one of the three women (Helen Willey and Marie Burcher were the other two) whose NACA employment was unplanned. Huckel had driven her grandmother across country from Long Beach, California, to Philadelphia, where her grandmother was to make her home. Since this was 1939, I asked her how long the trip had taken. She was unable to recall because they had stopped and visited relatives along the way and were not in any particular hurry. She was the sole driver on the trip. Having deposited her grandmother in Philadelphia, she decided to then drive to Hampton, Virginia, to visit friends who worked at the Hampton Veterans' Hospital. One of the friends she was visiting asked her to drive her to NACA to apply for one of the computing positions that had just opened, and Huckel decided she would also apply.

Huckel's career spanned thirty-three years, and she was one of only a few women to become an engineer. She is a very direct person who prefers to address only the issue at hand. During our numerous interviews, she answered questions very directly and never elaborated on her answers. If Huckel considered a question to be trivial, she would dismiss it by

saying "I don't remember things like that." Often supervising as many as 17 human computers, she states "You got to know your girls and gave them work they were capable of doing." It is interesting to note that all of the computers used the term "girls", a term no longer acceptable in reference to women. When asked if she ever had any problems with her girls, she replied that she never did. She said that she did have a girl transfer to her Section who had had problems in another Section because she had never worked for a woman supervisor before, but according to Huckel, this woman worked well under her supervision. Even after NACA allowed women to wear slacks on the job, Huckel never allowed her girls to wear them. She notes that a supervisor had to go to her boss if a girl was not working out well, and he would make the final decision about how to solve the problem, including firing the girl; while computers might become supervisors of computing pools, they were limited to supervising the work and had no authority beyond that.

Helen Willey, the next computer to arrive, had moved with her husband from Delaware to the city of Newport News, where he had accepted a teaching position in the local school system (he was later made Head of the Business Department at

Newport News High School). A neighbor asked her to accompany her to NACA to apply for a job, and like Huckel, Willey filled out an application and was hired. Since anyone hired had to agree to a minimum six months employment, she agreed to work for that period of time. Willey was uninterested in longer employment at that time because she wanted to start a family. She had had to delay marriage because married women could not teach and she and her fiance could not live on his salary alone, so there had been a further delay in marrying. Willey states it was ironic that while her neighbor wanted a job at NACA but was not hired because she lacked the qualifications, she was hired even though she had not planned to apply. Willey further notes that at first she planned to stay only the required six months, but with the outbreak of World War II (she started her job two days before the bombing of Pearl Harbor), she felt it was her patriotic duty to stay on, and each time she considered leaving, usually with the birth of one of one of her two children, she found she enjoyed her work too much to leave. She notes that her planned six month career went on for thirty-one and a half years. A quiet, soft-spoken woman, Willey spent her entire career as a computer supervisor, and



the women in this study who worked for her held her in very high esteem. When asked why everyone seemed to work together so well, she replied that "Everyone was young, they were all anxious for good paying jobs, especially the computers, and the common focus of the war and the need to get the job done."

Marie Burcher was teaching in the nearby city of Norfolk; when she came across to Hampton by ferry to visit friends, she was told about the better paying job at NACA. Since she majored in both mathematics and history in college, she was immediately hired and promoted to supervisor in a short time. Burcher notes that her double major in college enabled her to have two careers. Her first at NACA, which she left when she had her first child, and her later career as a historical interpreter at Colonial Williamsburg. Burcher is a vivacious and out-going person. Bielat, who dated Burcher before each married someone else, continues his friendship with her today and feels she was as vivacious then as she is now.

Three of the women, Rowena Becker, Kathryn Peddrew, and Barbara Weigel came directly from college. Becker started at NACA one month after graduating. It was one of her

professors who told her about the NACA bulletin. Peddrew states she had been brought up to feel that she could be anything she wanted to be. She discovered, however, that being female and Black were barriers for her. Peddrew had wanted a job doing research with her professor in New Guinea on the effects of quinine deafness, but had been turned down because she was female and there were no facilities for women on the team. She noted that this was a big disappointment to her. She read one of the bulletins published by NACA, and because she had majored in chemistry, she applied for a position in the chemistry division and was hired; however, when they discovered she was African-American, she was moved to the newly established and segregated Section in the Computing Division because the chemistry laboratory did not employ African-Americans.

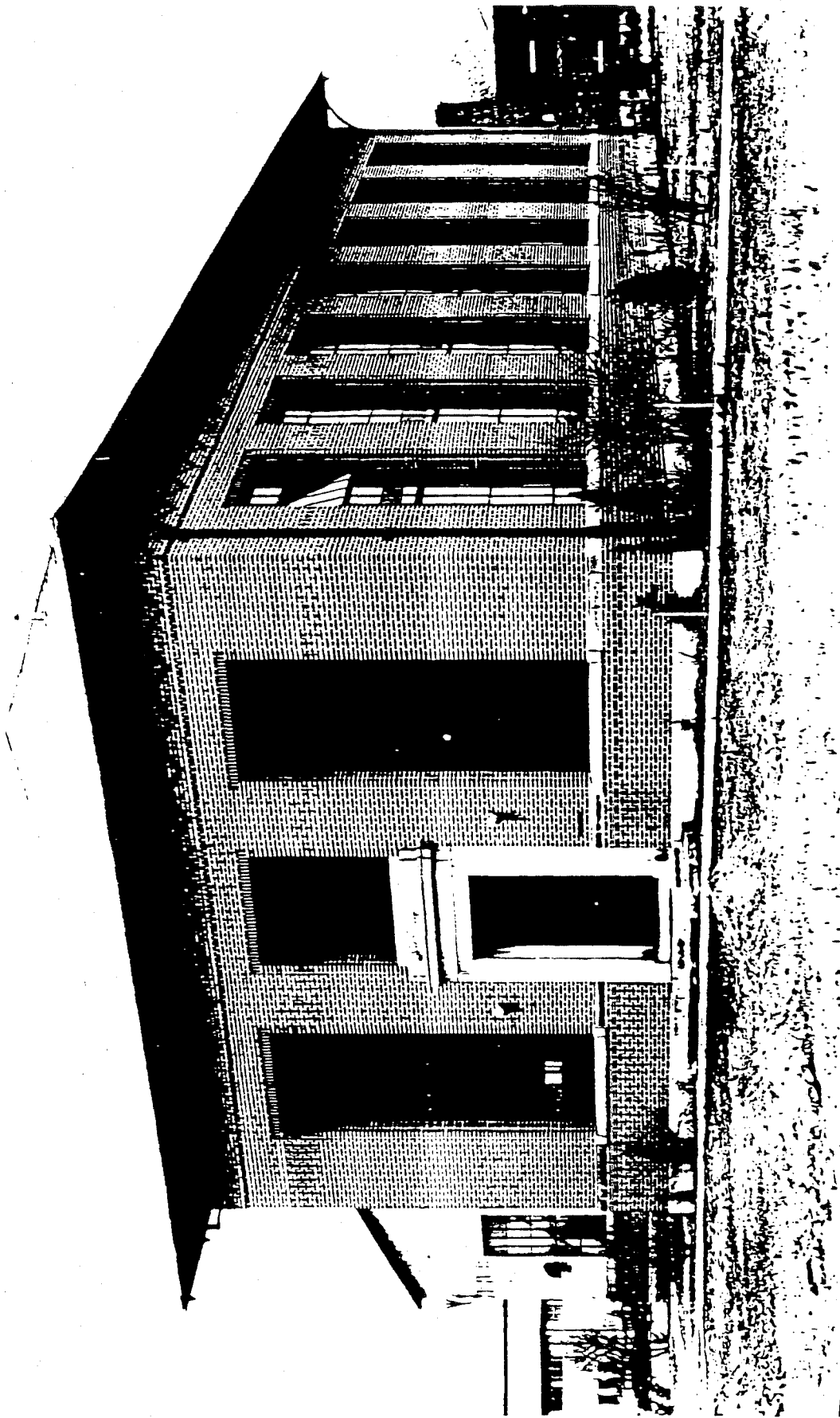
Barbara Weigel was a senior in college when she saw the NACA bulletin at school, and she applied through the mail and was accepted. Other than the teaching field, the only other computer who worked prior to coming to NACA was Betty Farmer. Farmer was working at the Census Bureau in Washington, D.C. when she applied for a position as a computer at NACA.

When asked why they studied mathematics in college and if their families had encouraged them to study mathematics (an unusual field for women in college in the early 1900s), each replied that she had been good in math in high school (one stated that she majored in mathematics because she did so badly in other subjects), and all replied that their families posed no objections to them majoring in mathematics. As several of them pointed out, however, their families did not object to their chosen major because she were expected to go into the teaching field and mathematics was an acceptable teaching subject.

In a 1942 Langley Research Center (LRC) memo about the viability of hiring women computers, it was noted that the increase cost in salaries would be minimal and justified because the computing time used by the engineers was "experience being wasted." The women were given the rank of Sub-Professionals (SP1) or Junior Computer, with a starting salary range between \$1,400 and \$1,600 with "one or two girls with five years service earning \$2,000." College graduates started at \$1,620. This memo also noted that private industry would probably pay slightly higher salaries for comparable positions. This need to justify hiring female

mathematicians and paying them less is interesting in view of the fact that while the males had degrees in mechanical or electrical engineering, they, too, had only bachelor level degrees. This type of attitude is what Margaret Rossiter (1982), calls "restrictive logic i.e., stereotypes, resistant barriers, and no-win situations" (Intro. xvii). She notes that in the figures for females graduating with degrees in the sciences for 1938, the figures for 291 colleges show a total of only 1,821 with 8.0 percent in mathematics and 3.2 percent in physics (p. 146-6). Rossiter further notes that for the year 1938 the salaries for male scientists was 40 percent greater than for female scientists (p. 222).

Vera Huckel had previously managed her step-father's office in an oil-related business in California, but was unable to recall what her salary had been. Helen Willey had been teaching for several years before her job at NACA. She relates she first earned \$90 a month for an eight-month teaching post. During this time she also paid \$25 a month for room and board. Two of her later teaching positions paid \$1,000 and then \$1,400. As noted earlier, she had been financially unable to marry when she first wanted to because women who married could no longer teach, a restriction not





imposed on male teachers. Willey recalls that she was married in 1940 on the day Paris fell. She also romantically recalls that prior to her husband accepting a teaching position in nearby Newport News, they had lived in a converted schoolhouse in Delaware, where her husband had a teaching position.

Rowena Becker came to Hampton directly from college and was invited to room at a Dr. Wright's home because the Wright family felt it was their patriotic duty to help to house NACA employees. She relates that she and her roommate babysat for the Wright's children. Becker has always corresponded with her mother by letter over the years. She says that the monthly letters from her mother who is now blind, are a challenge to read. Because of her blindness, her mother sometimes types on the wrong row of the typewriter keys and Becker and her husband have to "translate" the letters to the right keys. Marie Burcher had been earning \$810 a year in her teaching position before coming to Hampton where she roomed with a private family who had a daughter working for NACA. She states that four other women also roomed with this family.

## THE HISTORY OF N.A.C.A

In 1903 with the successful flight of the Wright brothers' airplane, the development of heavier-than-air craft began. Two precedents were established: the building of aircraft and an acceptance that there would be some errors in aircraft design. This rapid and trial-and-error approach was costly both in lives and money. The crude and limited use of aircraft in World War I paved the way for the development of the military uses of planes and the need for scientific investigation into aircraft design, especially by the United States since it had the fewest number of aircraft at the start of that war. Attempts by Samuel P. Langley, Secretary of the Smithsonian Institution, (for whom Langley airfield was named) and his successor, Charles D. Walcott, to establish a scientific study of aircraft were thwarted by political, legal, and social problems. Although Langley had vigorously championed the idea of establishing an aeronautical research center, one was not established until nine years after his in 1906. An interesting note is found in a 1991 reprint of the wording of the lease for land adjoining Langley military airfield for research in which



the sixth condition is for the removal of all buildings and the restoration of the land in the event the research discontinued. While this would be environmentally praiseworthy, it shows that there was a certain amount of skepticism about the future of aeronautical research.

It was not until 1915 that a committee was appointed by President Wilson to establish a scientific approach to the development of aircraft. This committee was named the National Advisory Committee for Aeronautics (NACA) and was given an appropriation of \$5,000 for five years. The first committee was headed by Brigadier General George P. Scrivens, and the clerk to the Acting Secretary, John Victory, who was later named Secretary in 1927. Victory was so admired for his management of NACA, a road built during the second World War that cut through the city of Hampton to NACA was named in his honor. This road, like so many names that were changed with the rapid advancement of NACA, was also later changed to Mercury Boulevard in honor of the Mercury capsule flight. The first site selected was land adjoining Langley military airfield in Hampton, Virginia. This site was selected because of its closeness to the airfield and reasonable proximity (via overnight steamer) to

Washington, D.C. A medical report by Acting Surgeon General A. H. Glennan in 1916 stated that although malaria fever was to be found in the Hampton area because of its location in a tidal basin, with proper precautions (the primary one being screening on windows) there were no serious medical problems associated with Hampton. In 1918 the first aeronautical research facility was begun and named Langley Memorial Aeronautical Laboratory (LMAL). This title was later shortened to Langley Research Center (LRC), which was used until it was again renamed the National Aeronautics and Space Administration (NASA) in 1958.

One of the first of the several men who recognized the need for aeronautical research was Jerome Hunsaker. In a report written in 1942 for the *Journal of the Franklin Institute*, Hunsaker stressed the need for aeronautical research stating "...research problems require time. But there is never time if the problems have not been foreseen...but problems of painful urgency result from disclosure of the enemy's superiority." In his report to the Smithsonian Institution, "Forty Years of Aeronautical Research", written in 1956, he notes that his awareness of the need for this development was heightened after a tour of European aeronautical research facilities in 1913. He reports that when World War

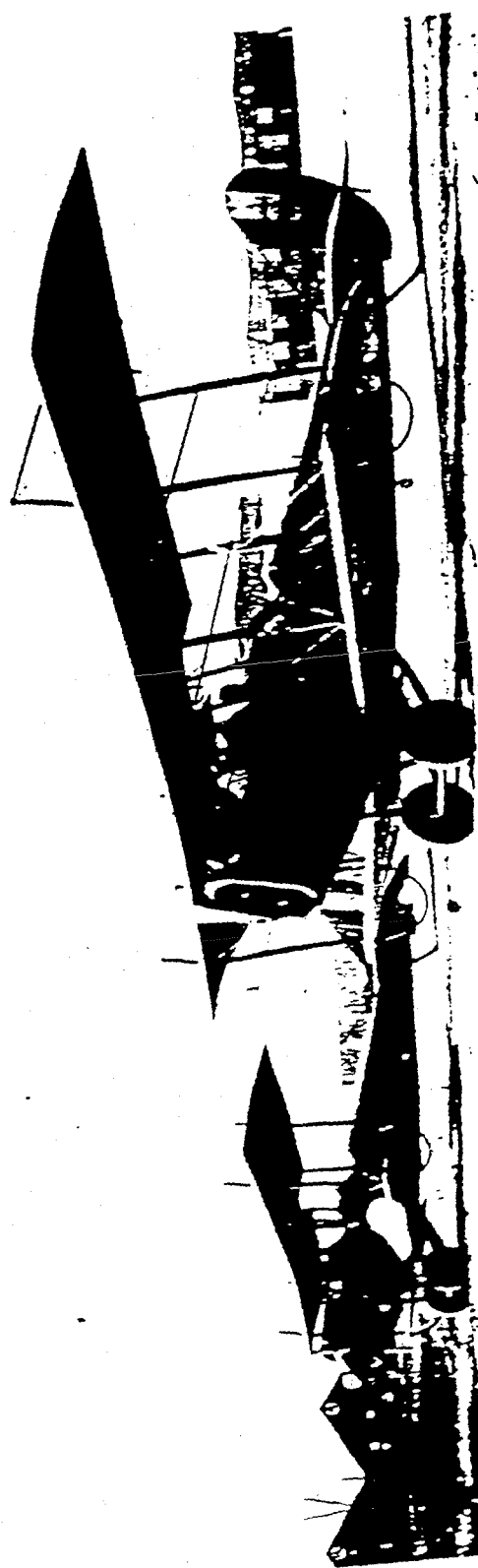
I started in 1914, France and Germany had over one thousand airplanes, Russia and England had just under one thousand, while the United States could count only twenty-three. A NACA committee was organized in 1909 with 12 new members appointed as the full committee in 1919, but this committee was only scheduled to meet semiannually, with the Executive Committee meeting at times throughout the year. Hunsaker also notes that by 1915 aeronautical research was being conducted only at the University of Michigan and the Massachusetts Institute of Technology (MIT); Worcester Polytechnic Institute was experimenting with "full-scale propellers mounted on a whirling table." Hunsaker, who been a scientist at MIT before becoming the Chief of Design at the Navy Bureau of Aeronautics in 1920, served as chairperson of NACA from 1941 to 1956, during which years he continued to play a vital role in the development of aeronautical research at LRC. As can be seen from this account, establishing the need for aeronautical research and the recognition of the likely increase in use of aircraft by the military was a difficult task. The human computers started arriving in 1939 (Vera Huckel was the first), and each has reported that they were immediately aware of the time pressure associated with the work.

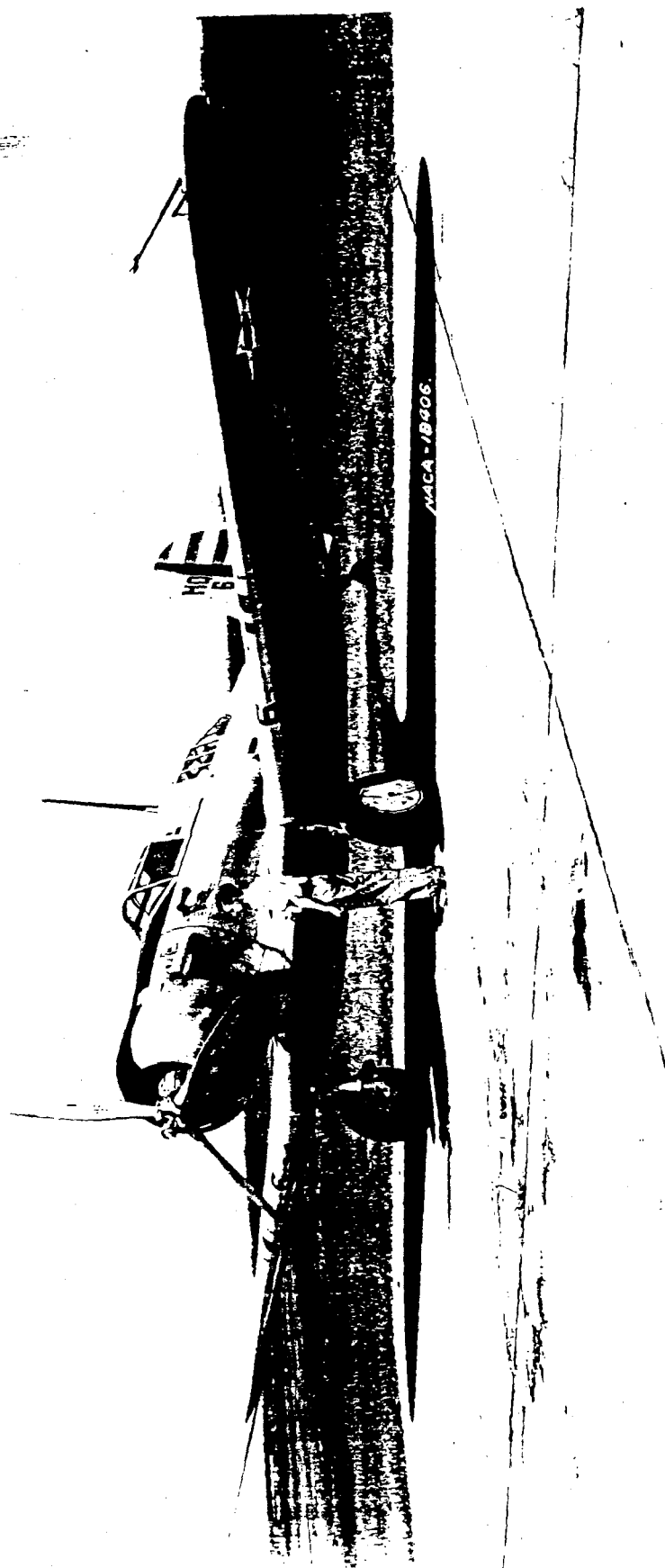
In 1939, with World War II underway in Europe and the need for aeronautical research even more pressing, a second laboratory was established at Moffett airfield in California and named Ames Aeronautical Laboratory (AAL) in honor of Joseph Ames, the executive chairman of NACA for its first twenty-four years. He had served as chairman of the executive committee from 1919 to 1936 and at different times on more than twenty subcommittees. Ames died in 1943. This facility was followed within a year by the construction of a third research station located in Cleveland, Ohio, first called the Aircraft Engine Research Laboratory, but later renamed the Lewis Flight Propulsion Laboratory in 1948 in honor of George Lewis, another NACA Executive Director. Since the women in this book worked only at Langley, the discussion will be limited to the research done at this facility and the part they played in it.

Where so much of the development of aircraft had relied on trial-and-error since 1903, the focus now became twofold: theoretical knowledge of aerodynamics and improvement in design of existing planes. Two of the earliest developments in aircraft design and development were metal coverings on

planes and the state-of-the-art engine called the Liberty. The shift was to the development of quantitative means of measuring aerodynamic flight. One of the first innovations was the development of inboard instrument panels to measure the forces on the aircraft by speed, flight, maneuvers, and time factors. The desired outcome was to be able to measure the performance of a plane to determine quantitatively if it was capable of the performance for which it was designed. One of the first realizations from the use of these instruments was the need for special training for pilots to fly research planes with probably the most famous of these test pilots being Capt. Charles "Chuck" Yeager, who became the first person to fly through the speed of sound in 1947.

Langley also developed the first wind tunnel in 1920. These tunnels were sometimes referred to as "wind channels", especially in the early aeronautical and engineering professional journals. The purpose of the wind tunnel was to replicate the effect of wind forces on an airplane using a model plane. Because the first tunnels were small, scale models of specific parts of planes were used. The human computers were assigned to Sections where they computed the research data obtained from these tunnel tests. One of the greatest advantages of this research approach was that



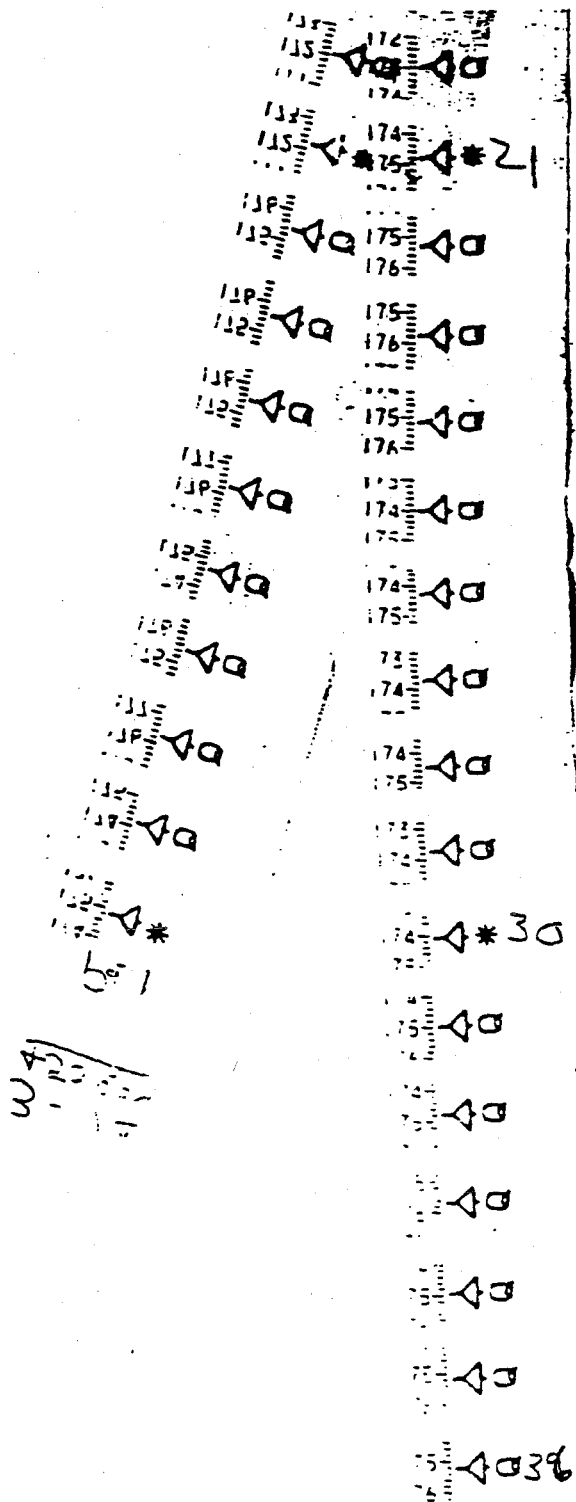


initial tests could be made without endangering the life of a pilot. The earlier in the air tests often ended in tragedy and were expensive in both human and monetary costs. However, even though tests could be made on pilotless models, it was still necessary to test tunnel results in actual flight, thus only greatly reducing pilot loss rather than eliminating it. This is still a risk that must ultimately be taken. A more detailed description of the development of wind tunnels is given later.

The first planes used in the tunnel research tests at NACA were two JN-4H "Jennys" built by Curtis Aircraft. These first tests measured lift (landing speed) and drag (maximum speed). Several more "Jennys" as well as other planes were obtained for this research. In later tests, by attaching orifices to the tail section, they read pressure distributions by having the orifices attached to a battery of what were called liquid filled manometers in which the readings could be recorded and photographed. Several other manometers were also developed to measure specific phenomenon, with all of the recordings needing to be photographed quickly for accuracy and then hand calculated for results. Figure 1. shows a manometer tape that had been photographed. This tape was provided by Helen Willey and is

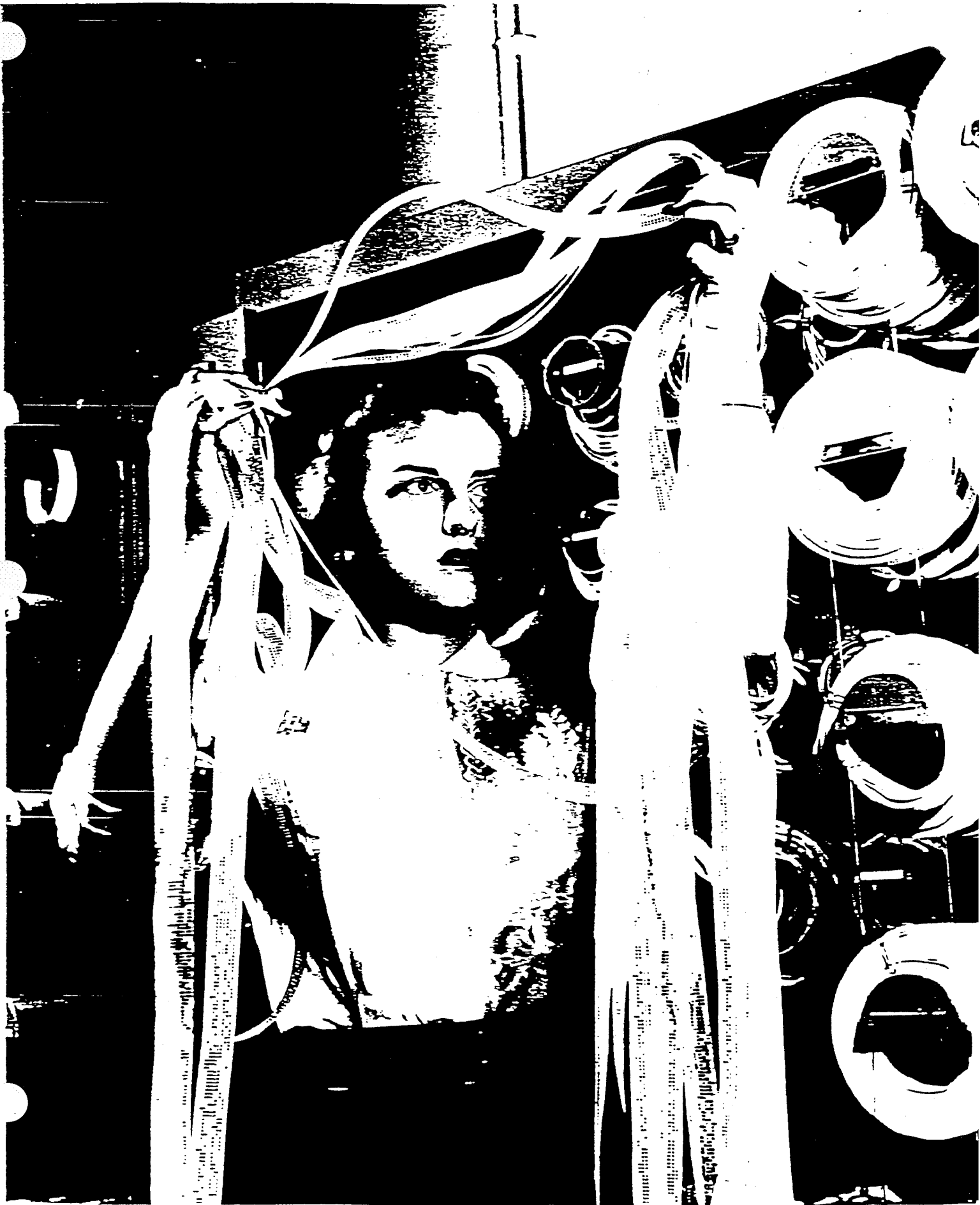


very likely the only one left in existence. The human computers report that prior to being able to photograph the manometer readings, two of them would be assigned to reading them; one would announce the reading and the other would record it. They report that reading and recording the manometer data was a very stressful job. The area in which they did this was small, dark, and stuffy. When they began to photograph the manometer readings, it was no longer physically uncomfortable for them, but their eyes became very strained from hours of reading the photographs and copying the data. Prior to the arrival of the human computers, the engineers themselves had had to do the reading of the manometers and the calculations that resulted. The process of doing the research and reading and calculating the data for results before further research could be done was what prompted NACA to hire women mathematicians to do this tedious but critical work. The urgency of the war and the rapid development of measuring instruments led to this need for additional personnel. Theoretical research became limited, but not eliminated once World War II loomed; Vera Huckel reports that she always worked in the Theoretical Division. The primary focus was shifted from basic research to what became described as "clean-up" tests i.e., aeronautical research on existing



MANOMETER TAPE

Figure 1.





- 1930 first application of optimum position of nacelles (wing mounted engines);
- 1931 first full scale wind tunnel;
- 1933 15-foot free-spinning tunnel;
- 1934 construction start for 8-foot 500 MPH wind tunnel;
- 1937 first free flight wind tunnel;
- 1938 12-foot free-flight tunnel;
- 1939 gust tunnel and 19-foot pressure tunnel;
- 1940 16-foot high speed tunnel and 20-foot free-spinning tunnel;
- 1942 seaplane impact basin operational;
- 1943 shift in research from piston to jet engines.

A total of six "firsts" were accomplished in less than twenty years. Frank W. Anderson Jr. in *Orders of Magnitude* (1981) quotes an eminent British engineer who said in 1929 "The only people so far who have been able to get at something like accurate results from wind tunnel experiments are the workers at the experimental station at Langley Field" (p.3). Anderson also notes that between 1941-44 the combined NACA laboratories worked on 115 different airplane types (p.7). In *Flight in America: 1900-1983* (1984) Roger E.

Bilstein says the 20-foot wind tunnel contributed conclusive studies on the value of retractable landing gear and the alignment of engines on the leading edge of the wing for multiengine aircraft, factors that drastically reduced drag penalties (p.70).

The reason for the success at LRC is expressed by Laurence Loftin, an Assistant Director, who stated that it was important for engineers to pursue their own ideas. He notes "It became very evident to me that if a researcher wants to do something, it's damn hard to stop him, he'll find a way to bootleg it." Bootleg projects meant that an engineer did work without prior approval, often to see if it was worth pursuing. Loftin goes on to note that "Some administrators thought bootlegging projects were a sign of researchers taking their own initiative." Ralph Bielat reported during an interview that when an engineer had a new idea he took it to the Division Chief who would assign others to help you put your idea into action. The model shop would provide the model needed, the human computers did the computations, and everyone worked together cooperatively. Bielat further noted that they "rode herd on each other during the development of a research project; each had knowledge of each other's work, so there would be a continuous exchange of ideas and suggestions."

During the next ten years LRC was instrumental in the design and development of many planes including the Bell X-1A (the Bell X-1 was the first rocket-powered plane) and the Bell X-5, Convair XF-92A, the Douglas D-558 and the Douglas X-3. The research became even more sophisticated and detailed. For example, it was discovered that rivets had to be flush with the surface in order to reduce drag even further. Mary Jackson was engaged in this research as an engineer. She stood on scaffolding in the wind tunnel moving the rivets an infinitesimal distance between recordings.

The P-38 fighter plane, one of the best at the time, flew close to the speed of sound (Mach 1) in a dive and experienced what was called "tuck-in", that is, a compressibility effect. The controls on the plane would not respond under this effect and the plane would crash to the ground. It was the engineers in the 8-foot tunnel who designed a dive recovery flap in the shape of a small wedge and located under the wing which, when applied by the pilot, automatically recovered from the high-speed dive. Because of the basic research done in the first twenty-five years of aerodynamic research and the early recognition of problems

that would only appear later, the development of space research and vehicle design was already underway. It is possible that it was the need to reduce theoretical research in response to the war effort that kept space flight from occurring sooner. For a closing example, as early as 1945 LRC's Robert Jones recognized that the relationship between a wing's attachment to the plane and the oncoming air was important in achieving supersonic speeds in planes. It is small wonder the human computers feel that their years at Langley were all exciting.

Another interesting part of the history of NACA is the response of Hampton, Virginia, to having been selected as its site. Hampton was a provincial town that relied on farming and fishing for its livelihood. This new research center brought in new people and new jobs. While the people of Hampton were friendly, nevertheless, there was a somewhat strained relationship between the townspeople and the NACA people. Marie Burcher comments that because she lived in a private home and attended a local church, she was able to more easily make friends and integrate into the community. She relates that she dated both "NACA boys" and "local boys", finally settling on a local boy for her husband.



Burcher suggests that the reasons for the strain were NACA brought in so many "outsiders" to this otherwise small town, these outsiders were largely more educated than the local townspeople, and most importantly, local boys graduated from high school, went to work for a short time and then were drafted while NACA boys were exempted from military duty. The people of Hampton apparently were not aware of the number of men from NACA who had voluntarily enlisted when the war broke out. Burcher also adds that NACA boys were often jealous of the attention local boys in uniform got from the young girls who worked at NACA.

The following quotes, printed in an anniversary issue of the *Daily Press* (July 12, 1992) give supporting evidence of the differences between the local population and NACA:

(I) remembered boat trips on the Chesapeake Bay, where NACA employees would help themselves to crab pots set out by the watermen. They worked hard and they played hard and the two didn't mix (Ira Abbott).

When Ford released new car models, they sent an engineer down to the local dealership to ask questions. NACA people asked all kinds of questions that the salesmen couldn't answer (Lawrence Loftin).

Langley employees had license plates on their cars that said NACA...remembers driving past the old Hampton High School, hearing the students chant, NACA NUT! NACA NUT!

According to Ralph Bielat, it did not help NACA's image when several engineers, including the famous Eastman Jacobs, when they attached a glider to the back of an automobile and tried to get it airborne on the most fashionable street in Hampton that parallels the Chesapeake Bay. He notes in addition, however, that many of the engineers married local girls and still reside in the neighborhood along the Bay, and that several of the engineers were musicians who joined the local symphony and musical groups.

Another group of young men working at LRC were the high school graduates who constructed the scale-models used in the research. These young men would work nights and rent "bed-sleeping time" in local homes during the day.

The first interview with Burcher was conducted over a cup of coffee at a local Ramada Inn, and the young woman waiting on us stated that she kept refilling our coffee cups because she was "so fascinated with the information" Burcher was relating.

Helen Johnson had been teaching in a nearby town where she had earned between \$680 and \$900 after six years of teaching. She lived with a family named Horseman where she paid \$30 a month for rent. She also relates that although she was earning much more at NACA than in her teaching job, she always ended up borrowing five dollars at the end of the month from Mrs. Horseman. Vivian Adair had been earning \$75 a month after six years of teaching first in South Carolina, then in Georgia, and later again in South Carolina. Adair stayed in a hotel in Hampton for three days waiting for confirmation of her job at LRC. She notes that the town was so small she could not get her traveler's checks cashed, even at the drugstore.

As an African-American, Kathryne Peddrew had trouble finding a place to live when she first arrived. When she left West Virginia to come to Hampton the train stationmaster told her he was unsure of where Hampton was, but he sold her a ticket to Newport News because he felt sure Hampton was close to that city. Newport News was better known because a large shipyard (the Newport News Shipyard and Dry Dock Company) had been built there that was already vital to the war. The first apartment Peddrew lived in is now the site of the new

courthouse. After marrying, she and her husband built the house in which she still lives as a widow. A petite and attractive woman, her comments, like Vera Huckel's were always direct and brief. Dorothy Vaughan also had the problem of race when she first arrived in Hampton. When she finally found suitable lodgings, she brought her children to Hampton where they have grown up and been educated. Vaughan has a son who presently works in the computer division at NASA. A reserved woman, she now leads a quiet life, and was too shy to allow me to take her photograph.

Barbara Weigel moved into Ann Wythe Hall (described later) and later shared an apartment with three other computers. Emma Jean Landrum also lived at Ann Wythe Hall. She recalls that she met Vivian Adair on the bus ride to NACA on her first day of work. Not sure of where to go, Adair gave her directions when they arrived at Langley. Adair continues to be an open and friendly woman. During several interviews, she was busy preparing for large dinner parties she was giving. Landrum, a tall stately woman, relates that she had gone to college on a scholarship and was valedictorian of her class. She states she worked in the dining room during her first three years of college and in her senior year earned money correcting papers for two of her professors.

She is very proud of the fact that when she earned her master's degree at the College of William and Mary in 1961, she was the first woman to get a master's degree in physics at that college. She expresses little tolerance for young people today who say they cannot to to college because they lack the money. Margaret Block roomed in the Garrett house located on Chesapeake Avenue. She later shared an apartment with two other women until she married. Her appearance today is very similar to the photographs taken of her during the years she worked at NACA.

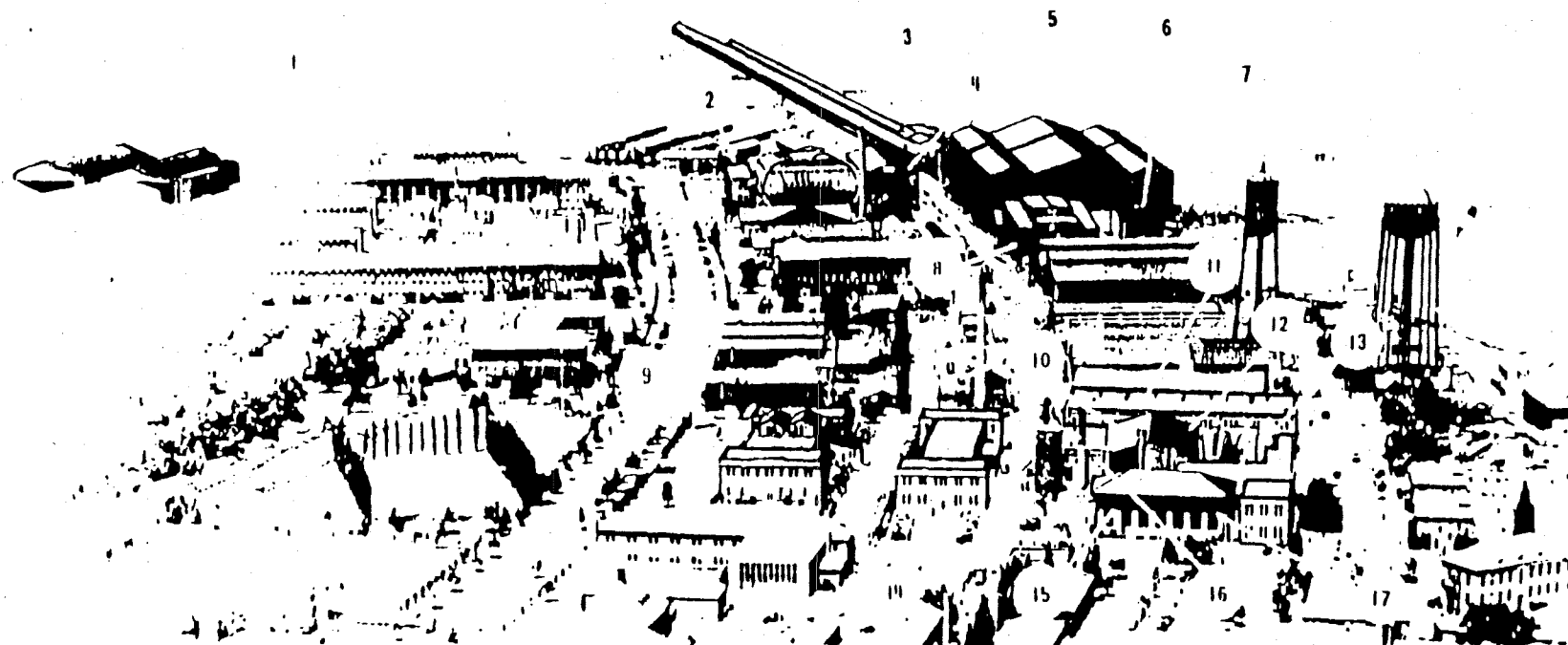
Mary Jackson, the third African-American in this study, did not have a housing problem after leaving her teaching post in Calvert County, Maryland, to come to Hampton because she was returning home to care for her ailing father. Since two other members of her family were teaching in the local school system, she was unable to be hired as a teacher so she took a job as a typist at Fort Monroe, a nearby Army installation, until she was hired at NACA a month later. Since she began her employment at NACA later (1951) than the earlier computers, her starting salary was \$3,410. Still a highly energetic woman, Jackson remains active in church and civic work. Betty Farmer sent part of her \$200 a month NACA

salary home to her mother to save for her; however, she always ended up asking her mother to return it to her before the end of the month. She relates that she always had problems managing finances in her early working years.

There were social, political, and legal limitations imposed on women during these years, especially when compared to the freedom of movement and choices women have today. First, as noted earlier, it was unusual for women to have jobs away from their families and hometowns. More importantly in the case of these women, there were limitations imposed by the wartime conditions. While few women owned cars, everyone was subjected to gas rationing, which limited mobility. Also, it was unacceptable for women to go out socially, especially at night, unescorted by a male. Their limited funds and the importance of a "good reputation" were additional restrictions. All of the computers report that the focus at that time was on the war; it became central to their lives. This is why most of their memories of those years are the work they did at NACA.

## HUMAN COMPUTING

The working conditions for the computers were dictated by the quick decision to create computing sections, the urgency of the war, and the limitations of the LRC facility at the time. With the exception of Vera Huckel, assigned to Theodore Theodorsen's office in 1939 as the only female computer, all of the computers were assigned to Section pools for their initial training. After a month in the East Area Computing Section or pool, for instance, Willey was selected to be sent to the 8-ft High Speed Tunnel where John Stack was Section Head and wanted his computing done on the spot. In 1942 Burcher was sent to join her and Becker and; and Johnson sent shortly thereafter. Block was later assigned to this same Section in 1951. The 8-ft computing Section grew to as many as 15 during the war years. Another decision made in assigning Sections was to segregate the computers by race, so Kathryn Peddrew, Dorothy Vaughan, and Mary Jackson were sent to the new West (Black) Section. Many of the white human computers were unaware of the West



Aerial View of Langley Memorial Aeronautical Laboratory, Langley Field, Va.

# EAST AREA

- |                              |  |   |
|------------------------------|--|---|
| 1 Flight Research Laboratory | 6 8-Foot High-Speed Tunnel               | 13 Two-Dimensional Low-Turbulence Pressure Tunnel |
| 2 19-Foot Pressure Tunnel    | 7 East Substation                        | 14 Service Building                               |
| 3 Tank No. 1                 | 8 Propeller-Research Tunnel              | 15 Atmospheric Wind Tunnel                        |
| 3 Tank No. 2                 | 9 Administration Building                | 16 Maintenance Building                           |
| 3 Dynamic Model Shop         | 10 24-Inch High-Speed Tunnel             | 17 Rectangular High-Speed Tunnel                  |
| 4 East Shops                 | 11 Utility Building                      |   |
| 5 Full-Scale Tunnel          | 12 Two-Dimensional Low-Turbulence Tunnel |   |





Aerial View of Langley Memorial Aeronautical Laboratory, Langley Field, Va.

#### WEST AREA

- |   |                                   |                                   |
|---|-----------------------------------|-----------------------------------|
| 1 300 MPH 7- by 10-foot tunnel          | 7 16-Foot High-Speed tunnel       | 15 West Shop                      |
| 1 High-Speed 7- by 10-Foot Tunnel       | 8 Stability Tunnel                | 16 Warehouse                      |
| 1 7- by 10-Foot Tunnels Laboratory      | 9 West Model Shop                 | 17 Sheetmetal Shop                |
| 2 Electrical Building                   | 10 Power Plant                    | 18 Lumber Storage Shed            |
| 3 New Heating Plant                     | 11 Model Supersonic Tunnel        | 19 Physical Research Laboratory   |
| 4 Impact Basin                          | 12 Gust tunnel                    | 19 Flutter Tunnel                 |
| 5 Aircraft Loads Calibration Laboratory | 13 Aircraft Loads Laboratory      | 19 Supersonic Sphere              |
| 6 Induction Aerodynamics Laboratory     | 14 Structures Research Laboratory | 20 Instrument Research Laboratory |

Section, including some of the women in this study. These three African-American computers report they not only had segregated working conditions but also had segregated dining and restroom facilities as well. All employees could purchase their lunch daily (lunches were very inexpensive) and were billed for them at the end of the month. Peddrew, Vaughan, and Jackson note that there were no African-American female computer supervisors or African-American male engineers in the early years. Each also expressed some bitterness about the segregation, but none toward the engineers, white counterparts or the way they were otherwise treated. If the work load became too much for a Section to accomplish in the needed time, computers were shifted around in the Sections to help with the additional work, so there was limited and brief integration at times. Both the African-American and white computers report that whenever this became necessary, everyone worked well together without any problems. It is also reported that when work loads became too heavy for a Section, the extra work that was sent to the segregated West Section was the less interesting and more tedious work. Vaughan states she was not made a supervisor until 1958 and says "I changed what I could and what I couldn't, I endured." Jackson, who arrived in 1951, notes that even after they began to integrate the computers,

one still had to "know" which restrooms were for which race. She was the first African-American computer to be integrated when she was sent to the 4 ft. tunnel.

Almost everyone also had to do night shift work. There were several reasons for two shifts: the amount of work to be done, the limited number of calculating machines, and the need to share the electric power with the wind tunnels. Due to war conditions and limited capabilities, the local utility company could not provide enough power to run all of the wind tunnels and their Sections simultaneously. The utility company also offered reduced rates for the electricity used at off-peak hours (a practice still used by utility companies). This electricity shortage necessitated delaying test runs with some tests not run until the evening. It was not uncommon for engineers to work all day and then all night in order to get their tests completed. As will be noted later in the section on wind tunnels, LRC was hesitant to hire any computers who were unwilling to work the night shift if necessary. Everyone worked a six-day week, including holidays with the exception of Christmas Day. If necessary, they even worked on Sundays. When asked to comment on working nights, holidays, and Sundays, the

computers stated there were no complaints because it was wartime and the jobs had to get done. They recall they were only sent home if there was a hurricane warning or the weather was too hot to bear. Because there was no air conditioning in these early years, heat and humidity had a bearing on the working conditions. Emma Jean Landrum reports that if she was not careful to sit upright in her chair, the back of her blouse would be covered in varnish from the chair. Barbara Weigel states she fainted at her desk one day because of the extreme heat and humidity. Humidity presented an especially difficult problem because the moisture on their arms would sometimes smudge the figures on which they were working. Working conditions were much stricter then than we see today; employees were not allowed breaks during the work day. Weigel reports that although there were water fountains in the hallways, there were no Coke or coffee machines in those days, and they could not leave the building to go to the cafeteria to get a drink except at lunch time. Marie Burcher notes that when she was a supervisor, she felt the women were better off working than thinking about the heat, so she just made them work; however, this was reported to the engineers, and she had to let the girls go when the weather got too oppressive. It was the mid 1950s before the computing rooms were air conditioned.

Burcher, like the other human computers, reports that the women all worked well together and were very supportive of each other. She recalls that one of her computers was a Jewish girl from Germany who had seen her father taken away by the Nazis. When arrangements were made for her to go to the United States to live with an aunt, her mother, unable to accompany her daughter, fainted at the train station. This young woman went to New York frequently to check lists to see if either of her parents had survived. She had taken a job at LRC because she was following a young Catholic soldier on his assignments. Burcher states that everyone was sympathetic, but did not seem to be able to console the young woman or get her to follow their advice. The young woman left and was never heard from.

When working holidays or Sundays, if one did not have a riding combination (explained later), transportation was a problem. There would often be limited public transportation, especially late at night. On one holiday night, several of the computers felt fortunate to have a young airman from Langley Air Force base give them a ride into town; they would have otherwise had to walk the several miles. Dorothy Vaughan reports that she was uncomfortable going home late

at night because she had to take a bus to Hampton, transfer to a trolley to get to Newport News where she lived, and then walk 14 blocks to her home. She notes that she was never bothered by anyone even late at night. Kathryn Peddrew felt less fearful returning home late at night because the police in Hampton knew the people in the neighborhoods which they patrolled and were good about checking the streets where women lived. She states that neighborhoods seemed much safer then, and no one bothered to lock their doors at night. Rowena Becker reports that she was never uncomfortable taking public transportation even late at night. She recalls that she once lost her watch at night, but found it on the sidewalk the next day. Betty Farmer recalls that on her previous job at the post office in Washington, D. C., she worked until 2:00 A.M. and the bus driver would time the traffic light so that he had to stop at her street and he could watch her walk to her apartment before proceeding on his route.

The computers were assigned to different Sections, but essentially did the same kind of work. There was a Section Chief Supervisor (herself a computer) who assigned the work to each computer, although according to Willey, it was not uncommon for an engineer to ask for a specific computer to

do his work. Most of the computers stayed on a particular project from its beginning to its completion, which could run from months to years. Although several of the computers worked in more than one tunnel, especially those who worked for many years, each describes working in a particular type of research: Huckel worked in flutter and vibrations (her work in sonic boom testing is described in detail later in the book); Willey in high-speed and later, after the transformation of the 8-foot tunnel to a transonic facility, transonic and supersonic research; Becker in pressure distributions and other high speed research; Burcher and Johnson in the 16-foot tunnel (Johnson later did the editorial work on plots and figures for the reports written for the 8-foot tunnel); Adair in variable density; Peddrew in balance in the Instrument Research Division; Vaughan in flight paths; Weigel in structures (theoretical); Landrum in air flow and the transonic and supersonic tunnels; Block in transonic research; Jackson in supersonic research; and Farmer, who arrived later (1958), exclusively in electronic computing. While all of the work the computers did was classified, some of them also worked on highly secret research projects.

Shortly after the computers were first hired, LRC installed special desks for them, which were made on site. These LRC

built wood desks had a well on the left side which held the calculating machine. Some computers calculated with their right hand and and fed the information into the calculator with their left hand while others performed both operations with the right hand. They later made right-sided desk wells for those who were left-handed with the first one made for Ann Merfeld (Ann later married Axel Mattson, one of the engineers included in this study). The engineers also designed, but did not build, a huge chair for Merfeld after the chair she was sitting in broke under her. This design (and its purpose) was jokingly featured in a 1945 edition of an in-house newspaper.

These desks did not present a problem for Vivian Adair who had a handicap she had been coping with since early childhood. She had contracted a disease which affected her nervous system and manifested itself by a reversal of commands; when she attempted to do something with her right hand, her left hand performed the chore. Adair is still amazed at the fact that her mother worked very hard to help her overcome this disability by asking the college coach in her hometown to work with Vivian to correct her problem. She states this innovative approach preceded physiotherapy by years. Adair proudly reports that because she lived in a





neighborhood with all boys and was very competitive, she learned to adjust her hand responses in order to play baseball and football with the boys. Her coping skill at LRC was to memorize the numbers and then put them on the calculating machine with one hand, while the other computers used both hands to accomplish this transfer of numbers.

Margaret Block recalls that one computer wrote with her right hand and put the results onto the Friden calculator with her left with a cigarette dangling from her mouth. Block was fearful this computer would set fire to the data. In later years when new desks were purchased, Helen Willey bought one of the old desks from government surplus for her son. This desk is now used by her grandson. It is noteworthy that Willey worked the longest as a computer supervisor and was very admired by everyone. Block remarks that when she and several others went to the retirement party for Willey there were so many in attendance they were fearful there would not be enough food for such a large turnout, so Block and these other women ate at a nearby restaurant after the party.

In discussing the use of right and left-handed desks, Emma Jean Landrum notes that, although she was left-handed, she



TABLE VIII.- SUMMARY OF DATA POINTS AND MODELS AT EACH MEASURING SECTION FOR VARIOUS FLOOD CONDITIONS

Table	Airplane	Altitude above ground in feet	Station 1			Station 2			Station 3			Station 4		
			Number of data points	As, sec	Time	Number of data points	As, sec	Time	Number of data points	As, sec	Time	Number of data points	As, sec	Time
1	A	1000	10	1.0	10.0	10	1.0	10.0	10	1.0	10.0	10	1.0	10.0
2	A	2000	20	2.0	20.0	20	2.0	20.0	20	2.0	20.0	20	2.0	20.0
3	A	3000	30	3.0	30.0	30	3.0	30.0	30	3.0	30.0	30	3.0	30.0
4	A	4000	40	4.0	40.0	40	4.0	40.0	40	4.0	40.0	40	4.0	40.0
5	A	5000	50	5.0	50.0	50	5.0	50.0	50	5.0	50.0	50	5.0	50.0
6	A	6000	60	6.0	60.0	60	6.0	60.0	60	6.0	60.0	60	6.0	60.0
7	A	7000	70	7.0	70.0	70	7.0	70.0	70	7.0	70.0	70	7.0	70.0
8	A	8000	80	8.0	80.0	80	8.0	80.0	80	8.0	80.0	80	8.0	80.0
9	A	9000	90	9.0	90.0	90	9.0	90.0	90	9.0	90.0	90	9.0	90.0
10	A	10000	100	10.0	100.0	100	10.0	100.0	100	10.0	100.0	100	10.0	100.0

Figure 10.



NABA  
L-72-6294

operated the calculator with her right hand. She recalls that at one point she had to use a left-handed desk and and operate the calculator with her left hand because of the damage to her right wrist from over use. She explained that the tunnel in which she was working was an outside tunnel with a tall exhaust stack over a concrete pillbox. Because it was located outside, it was subjected to the vagaries of weather, especially humidity. She says they often had to wait for days for the humidity to drop so they could run tests. Since it was decided it would be too expensive to cover the existing stack, the engineers decided to reduce the height of the stack so that it could be enclosed within a cover; the air would come in through this pillbox into the tunnel and then be exhausted out the stack. Unsure how much they could reduce the stack without affecting the exhaust flow, the engineers cut it in increments of a foot at a time, would then calibrate, and then cut again until they got a height which could be reasonably covered which did not upset the exhaust flow characteristic. Landrum describes the final building as looking like an inverted thermos bottle. She states it was her job to run the calculations for each calibration that was done and that hour after hour of calculating damaged her wrist.

Each Section had from three to 20 computers and each Section provided a different set-up for them with many of them makeshift arrangements. For example, Helen Johnson reports that when she first went to the 8-foot tunnel her three-computer group were housed in a cubbyhole, while Emma Jean Landrum reports she was in a glass enclosed balcony which was really a hallway. Margaret Block states she first worked for two years in an Air Force building along the Langley flight line, later moving into the new 8-foot office building where "the view was fabulous." Marie Burcher recalls that her computers were housed in a glass enclosed section of the shop where the scale models for testing were made, causing it to be a very noisy working environment.

Rowena Becker fondly recalls that from where her desk was situated, she could look out at the Back River and watch the sailboats on the river while working. She often went sailing on the river with the engineers and other women; it was while sailing that her romance with the engineer John Becker, whom she married, first started. John Becker and another engineer named Donald Baals were responsible for a great deal of the testing on the famous World War II bomber, the B-29. John Becker served as Division Chief for 27 years.





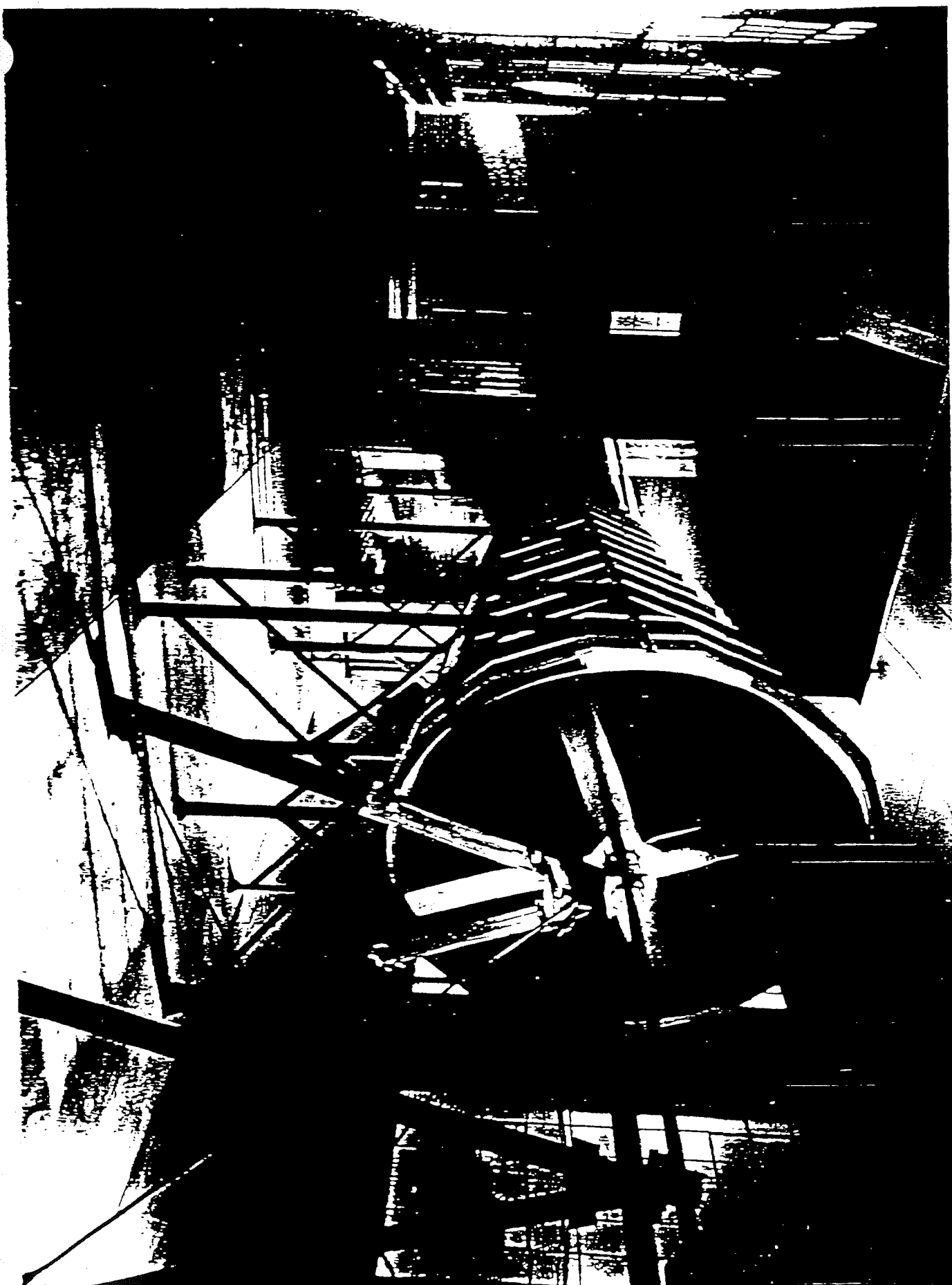
Becker also reports that the test room surrounded the tunnel chamber; therefore it was necessary for the computers to go through a pressure chamber before entering the test section and return through the chamber following the tests. Vera Huckel was the only computer who was not first sent to an open Section. She notes that she always worked in Theodorsen's office with the male Junior Engineers.

Theodorsen, recruited by Ames in 1929, was an expert in flutter and theoretical pressure distributions on airfoils (wings). Huckel also reports that in the early years, with the exception of the chief engineer, John Stack, very few engineers had private offices. Most of the engineers were housed together in each Section, but had better facilities than the computers. When Theodorsen left in 1946 to move to South America to work, he asked Huckel to accompany him, but because she was unwilling to move so far away, she declined. She next worked for Edward Garrick who replaced Theodorsen as Chief of the Dynamic Loads Division.

Because the human computers performed the mathematical calculations on the data obtained from the tests done in the wind tunnels, the history and a description of the wind tunnels is given here in order to understand the research problems and the methods used at LRC to investigate these problems.

The first wind tunnel was built in 1920. The building was only 10 by 14 feet in length and 23 feet high, and the tunnel section was constructed of wood (see photograph). Scale models of parts of planes were suspended from wires in the cylindrical tunnel section which ran through the center of the building. The engineers sat below this tunnel and read the data obtained from a modified ordinary Toledo weighing scale; the force of the resistance was translated into pounds. This first tunnel could measure speeds up to the then unheard of speed of 120 mph. As aerodynamic knowledge increased and research questions developed, it was also necessary to develop wind tunnels of various sizes and functions in order to measure specific and different tests because no one tunnel could test all conditions, a factor still true today. As of 1954, the period included in this text, there were 200 wind tunnels with the largest number and widest variety of them at the Langley Research Center. The first tunnel was called a 5-foot atmospheric wind tunnel. The following is a detailed description of this tunnel written by Elton W. Miller in 1924:

A five foot cylindrical experiment chamber of the closed type with entrance and exit cones, and mounted inside a large steel tank in which the air pressure may be varied from .1 to 20 atmospheres.



An annular return channel for the air is provided between the shell of the tank and an outer cone. The air is circulated through the tunnel by a propeller at the end of the exit cone. Between the inner and outer cones, is a space filled with air at rest in which the balance is situated. The model is supported from the balance by wires or by a spindle...The spindle when used, projects forward from a movable bar of the balance, which passes vertically through the center of the channel within a streamlined fairing. The balance is operated by electric motors from control switches outside the tank. Observations are taken through a peep hole in the shell. The propeller is driven by a synchronous electric motor having a drive shaft which passes through a stuffing box in the end of the tunnel. Electrically driven air compressors are used for delivering compressed air to the tunnel, or rarefying the air within.

This tunnel was replaced in 1929 by a 5-foot vertical tunnel, and the following year by a 7-foot atmospheric tunnel. The rapid development and construction of wind tunnels is seen in the following abbreviated chronology and description: (A full chronology is given in Appendix A.)

1920 5-foot tunnel operational

1922 variable-density wind tunnel (steel cylinder 15 by 34 feet) to conduct research into the high Reynolds numbers and investigation of propeller blades approaching speed of sound.

- 1927 propeller research tunnel for full scale tests on propellers, fuselages, landing gears, tail sections, and model wings of large size. (This was the first wind tunnel to measure full size airplane sections.)
- 1939 a 19-foot pressure wind tunnel to obtain high Reynolds number tests, particularly fo propellers at speeds close to actual flight speeds.
- 1944 8-foot High Speed tunnel built.
- 1947 Annular Transonic tunnel to measure pressure distributions on air foils.
- 1948 4x4 supersonic tunnel with the capacity to use models large enough to install sophisticated instrumentation in order to measure viscous and interference effects.
- 1950 26 inch tunnel to measure flutter at transonic ranges.
- 1955 Unitary Supersonic tunnel for measurements of pressure distribution and heat transfer at high speeds.
- 1957 9-foot Thermal tunnel to test structural components for the effects of heating and loading.

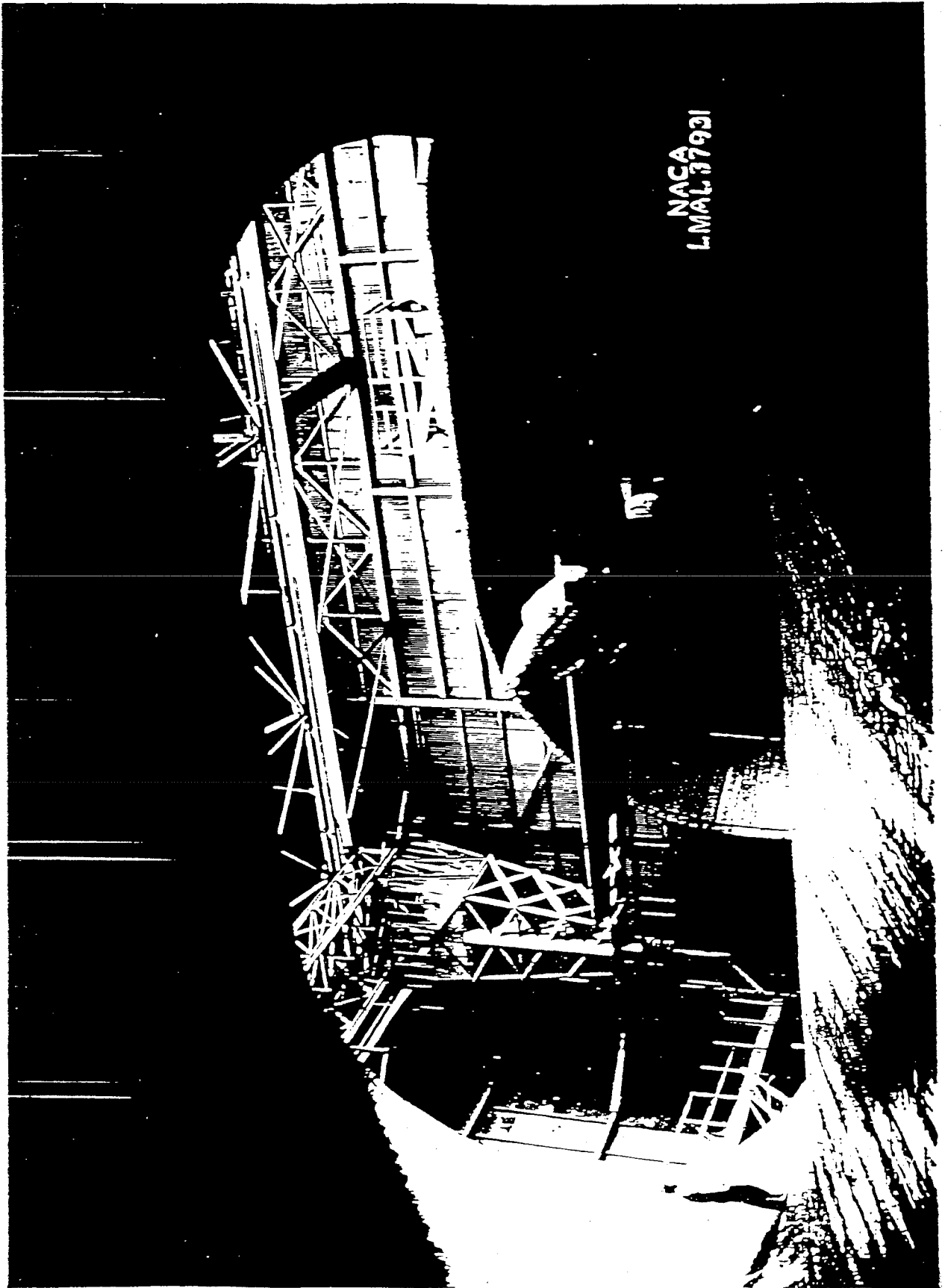
To better understand the functions of these wind tunnels several technical terms need a brief explanation. The first, Reynolds number, developed by Osborne Reynolds in 1889, refers to a number used as a criterion to determine if fluid

flow is absolutely steady or with small unsteady fluctuations (turbulence). This number is used to evaluate the behavior of a scale model to its full-scale prototype. A Reynolds number criterion of less than 2,000 is generally laminar (non-turbulent) while a number over 2,000 indicates turbulence. Viscous refers to having a relatively high resistance to flow; therefore, laminar flow would be the desired outcome of the research in aeronautical design. When Mattson worked in the 8-foot tunnel with Theodorsen, the expert in flutter, Mattson was assigned as the project engineer for tests on a pursuit plane in which the entire tail section fluttered off. He states they set up a model and "blew it apart to find the problem and fix it."

An important development in wind tunnel research was the designing of the slotted-throat. Wind tunnels are cylindrical in shape with openings at both ends; the middle portion is called the "throat" section. A recognized and frustrating problem in the design of the tunnels was that the tunnel walls interfered when waves met at the walls. The confinement of airflow to walls did not simulate the free flow of air found in actual flight. Several other wind

tunnel designs had been tried including wide open tunnels (no walls) and completely closed ones, but each of these designs created different and undesirable results. In 1946 Ray Wright, a theoretician, approached his supervisor John Stack, the Division Chair, with a mathematical model for slots cut into the tunnel to improve air flow. Stack, who later won a Collier Award in 1948 for the development of the slotted-throat tunnel, immediately put his prestige and influence into the development of this new concept. Ten narrow slots were cut into the 16-foot tunnel and the result was that they were able to go up to and through the speed of sound. While the concept was originally conceived for subsonic speeds (below the speed of sound), it enabled the engineers to now go to (transonic) and through Mach I (supersonic) speeds. Many tests for the number, size, and placement of slots were done before the exact slot configuration was determined. The slots were later replaced with a "mesh of holes" which compensated for some of the slots' weaknesses. The human computers were, of course, part of this research.

One of the most serious challenges to wind tunnel research was the difference in aircraft design and performance in the three speed ranges: subsonic, transonic, and supersonic. The



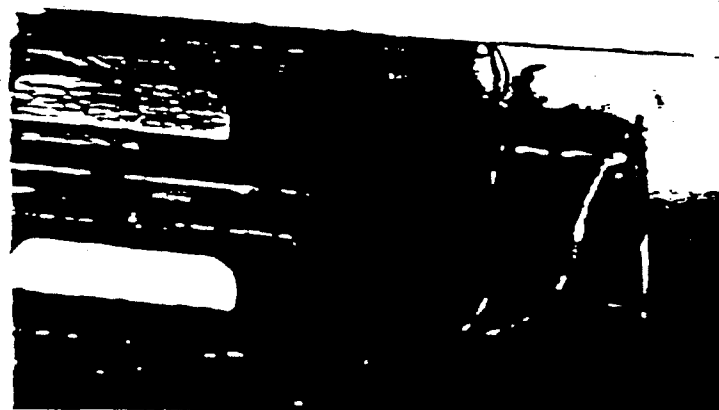
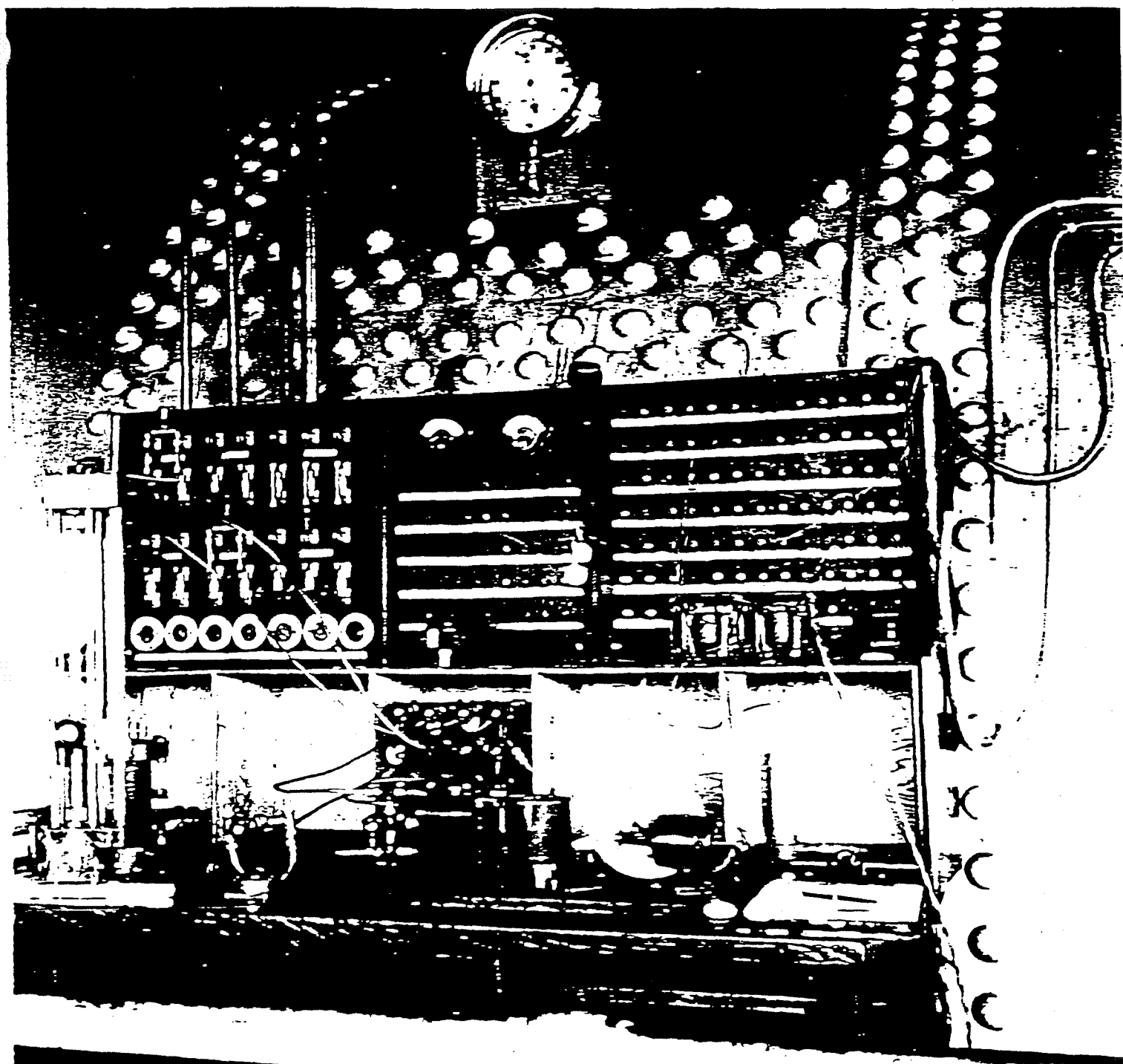
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transonic speed range proved to be the most difficult because of its overlap with subsonic and supersonic ranges. Transonic is described as "...a coexistence of mixed subsonic and supersonic flows; it does not have exact boundaries, and it varies with configuration." The design of aircraft to fly at supersonic speed must also incorporate the drag and control factors experienced in first going through the transonic speed range. It was not until 1951 that LRC was able to develop wind tunnels that could record accurate data throughout the whole transonic speed range. It was the slotted-throat modification in tunnel design that lead to this major research breakthrough. According to Bielat, new methods of supporting the scale-models in the wind tunnel for transonic testing had to be developed in order to minimize the large interference effects of conventional support systems. This need led to the development of sting support systems and internally mounted electric strain-gauge balances. A need also arose to measure the dynamic stability characteristics of the models at transonic speeds and this requirement led to the development of an internally mounted oscillating mechanism using a Scotch-Yoke drive. A Scotch-Yolk is a shaft driven motor with a crank which fits into a rectangular beam. As the

crank rotates, it causes the model to go into a different motion. The Scotch-Yoke can change the motion from one phase (rotary, pitching, or yawing) to another phase. These same principles were involved in the later design, testing, and development of space vehicles.

As noted by Helen Willey, the engineers, mechanics and computers worked as a team. The engineers designed the research, the mechanics built the scale models according to the research design, and the computers calculated the results of the tests on the models. Since aerodynamics was in its infancy, all the research was pioneer work. The research was both hampered and helped by the war. The urgency created by the war to improve existing aircraft and design new aircraft coupled with the paucity of aerodynamic principles provided a challenge to their creativity and innovation. As noted earlier, old fashioned Toledo scales were used to measure pressures until better wind tunnels and measuring instruments could be developed. During this phase of the research, using a 20-inch slide rule, the computers would plot each point on a curve to determine if enough points had been taken to give the desired information. Each development also provided the information about what improvements needed to be made. In order to accomplish this,



the research was done in small increments in order to determine the correctness of the direction being taken. For example, pressure distributions along the entire length of a wing had to be done in order to determine if the wing design created a laminar or viscous air flow and if it was viscous, how much change in design was needed to get a laminar air flow. It was also necessary to determine if the results were due to the angle at which the wing was attached to the aircraft. While doing the practical work of design, they were also determining aerodynamic principles.

In the very early years several means for measuring pressure distributions, resistance, and air flow were developed. One of the first was a manometer board. Tubes were attached to the scale-model in the wind tunnel and connected to a horizontal board. These graduated tubes contained carbon tetrachloride or mercury or other liquid which measured the pressure levels, and because these levels would be true only for a short time, it was necessary to quickly transcribe them on to paper. One computer would read the levels while another computer recorded them (It was noted earlier that this was a physically draining procedure for the computers.) These data would then be put on sheets of multi-columned paper. The sheets were headed by the

equations the engineers wanted them to use and the calculations to be performed (see Figure 2.) For example, the figures in column one might be added to the figures in column two and the results put into column four. They were given a constant and were to arrive at a coefficient. As a system for double checking the calculations, each computer passed the completed sheet to the next computer who recalculated the same data. If the recalculated figures did not agree, a red dot was put on the sheet which was then signed by the computer, and the work was passed back to the computer for recalculation again. All of the computers agree that very few sheets were marked with red dots. Ralph Bielat recalls that to relieve the intensity of the work with a little levity, the computers would sometimes plug their data into the calculators in a sequence so that the accompanying sound from all the calculators was as rhythmic as a marching band. He smiled when he recalled that the engineers would sometimes dangle rubber spiders over the dividers to frighten the computers.

Since the engineers were themselves unsure the results would be what they had anticipated, there would sometimes be several tests recorded on the same sheet which would be calculated and then plotted onto graphs. Bielat says the

LF-1003 Type run:

TEST NO. 120

D-558

JOB NO. \_\_\_\_\_

$P_a =$

DATE \_\_\_\_\_

$K_{TBE}$

Area (exit) =

59 ft

OBSERVER \_\_\_\_\_

$M$ approx.	Rdg no.	$P_t$ tube rdg	$P_a$	$P_a - P_t$ 0.1"	$P_a - P_t$ $16/H^2$	$P$	$H$	$M$	$B/H$	$P_s$	$P - P_s$	$F_p$	Cath. rdg
	0												
	1												
	2												
	3												
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COMPUTING SHEET

Figure 2 .

engineers would give the computers enormous amounts of data to calculate and plot. For example, if they were examining lift characteristics against the angle of attack, the data would need to be calculated and plotted for different Mach numbers plus drag characteristics (see Figure 3.)

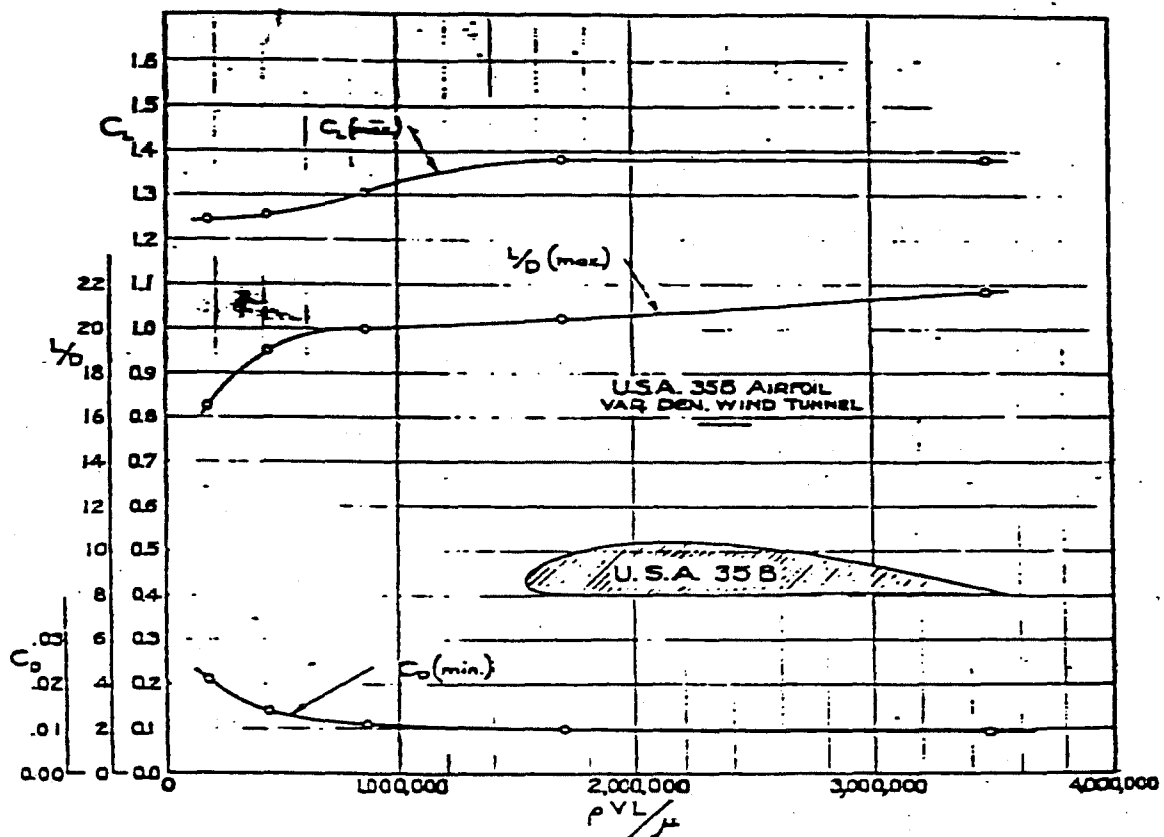


CHART SHOWING TYPICAL SCALE EFFECT ON AN AIRFOIL

Figure 3.

The data to be plotted might also involve the characteristics of pitch moment, lateral direction stability, yawing moments, rolling moments, and side forces acting on the aircraft model being tested. An engineer might then want this cross-plotted for final analysis. If needed, modifications would be made in the test design and the test and calculations redone. Data were then plotted on graphs using an integrator, a metal arm which traced the recorded points.

Since many of the computers worked for long periods of time in tunnels that performed particular kinds of research and often worked on projects from the beginning to completion, they became knowledgeable about the types of figures that should result. If the figures did not appear to be consistent, the computer could point this out to the engineer. All of the computers except Mary Jackson report that the engineers were receptive to their comments. Mary Jackson recalls that on one occasion an engineer who was a Division Chief, disputed her calculations until she pointed out that they were correct for the data she had been given. When the engineer recognized that he had given her the wrong data, he apologized. She says she enjoyed her increase in



status among the other computers that resulted from her having challenged the engineer's complaint.

Helen Willey states that there were times when the supervising computer was given raw data and she had to determine the equations and calculations to be used. One of Willey's promotions was based partly on her editing of a *Handbook for Data Reduction in the Eight Foot Transonic Tunnel* for the mathematicians, math aides, and engineers. An additional challenge to the computers was that when the research they were working on was classified, they were not always certain what the data applied to or what they were looking for. An innovation in the reading of the manometer board was to photograph the recordings. This was a big improvement because, as noted earlier, prior to photographing them, the computers had to work quickly in pairs in order to preserve the accuracy of the readings. In addition, since many tests were run and rerun, it often necessitated working in a small dark room for hours recording the readings. Emma Jean Landrum, promoted to the rank of engineer in the early 1950s, developed a gauge with a ruler on one side that enabled the computers to read all the data at once, whereas they previously had to use an eye

piece to read each level. The computers report that even with the ruler, this was still one of the most tedious and exhausting tasks they did. The Shlieren photographs recorded the shock waves that formed when air was pushed aside by an object (the part of the aircraft being studied). The studies of these shock waves enabled the engineers to discover two additional shock waves that also occurred. Unknown to him at the time, Richard Whitcomb, one of the engineers studying the shock waves, had discerned the principles that enabled him to develop the Area Rule in 1951. Whitcomb had been at Langley in the 8-foot transonic tunnel for nine years and was only 31 years old when he made his discovery. While the previously used "rule of thumb" had dictated that the fuselage of an aircraft had to be bullet shaped in order to reduce wind resistance, Whitcomb discovered that it was the entire aircraft that determined the amount of resistance. He therefore determined that the fuselage had to be "pinched in" at the point where the wing joined the fuselage in order to reduce the drag and resistance without having to increase the power. This Area Rule was critical in the development of aircraft for transonic flight, and with later modifications in design, for supersonic flight, the ability to break through the sound barrier (Mach 1). Although in the early 1940s the Nazis had developed missiles that flew through the

speed of sound (V2s), no aircraft had been successfully designed to accomplish this feat. Whitcomb was awarded the Collier trophy in 1955 for this work. He was later promoted to the head of the 8-foot tunnel, a position he held until his retirement.

A later innovation in taking motion pictures of the phenomenon, credited to Walter "Dick" Lindsey, was the duplex system which enabled the engineers to both see as well as record the shock waves. In a telephone interview with Lindsey who is now 82, he explained that in the Schleiren photographs a "knife-edge" marker was used to mark the shock waves, but were still photographs. Later, with the invention of motion pictures, it was possible to see this at more than the one point shown in the still photographs. At first they used arc lights to illuminate the recording of the air flow pictures, but later developed a high frequency flash system which, combined with the use of a Kodak Fast Tech camera, greatly improved the visual recording of the shock waves. In Lindsey's duplex system, he added a mirror inside the camera which enabled the engineers to view the phenomenon while it was occurring. This was critical work at the time in the development of a wing shape for transonic

flight. The motion pictures and mirror image enabled the engineers to determine that the shock waves were random and not at the high pitch and constant frequency that had been assumed (see Figure 4.) There are several examples throughout this text of serendipitous results similar to this that resulted from painstaking research. These results provided the principles which eventually led to the development of space flight.

Vera Huckel was one of only three of the 13 computers in this study to be promoted to the rank of engineer; Emma Jean Landrum and Mary Jackson were the other two. As noted in the Introduction, Pearl Young had been hired in the 1920s as an engineer, and Kitty O'Brien Joyner, a computer, had also achieved the rank of engineer, but these two women were not included in this study because Young is deceased and it was not possible to include Joyner because of her health; she has since died. Huckel's promotion record shows her progressing from Computer in 1939 to Computer Supervisor in 1945, and then to Mathematician in 1950. In 1962 she was promoted to Aerospace Engineer, and her last promotion prior to retirement was to Supervisory Mathematician in 1968, It should be noted that it was Helen Willey who helped to persuade NACA to upgrade the college graduate computers to

the rank of Mathematician since they had the same qualifications as the males who were hired as mathematicians, but did not work in the computing Sections. Willey retired in 1973 with the rank of Supervisory Mathematician having supervised in the 8-foot tunnel for her entire career.

#### RECRUITMENT

To recapture the conditions during the years the computers were at Langley, a description of recruitment, housing and transportation is given here. The rapid expansion of LRC is reflected in the figures for the periods 1938 and 1948; in 1938 LRC had 430 employees with 170 of them engineers, a budget of \$1,167,000, and capital investment in buildings and equipment of three million dollars. By 1948 these figures had increased to 2,950 employees with a budget of \$13,350,000 (the highest employment rate of 3,288 having been reached in 1944), The figures given for 1943 show that 2,000 were employed as compared to 1915 when there was one employee and 1916 when employment was only five. The newer

NACA facilities in Ohio and California had not yet been built in 1938, so LRC was the only NACA research facility at the time. The figures for post-war year 1958, the beginning of the change-over to NASA, show 3,250 employees with a budget of \$27,204,000; far larger than the one million dollar budget for 1938.

As early as 1936 George Lewis, Director of NACA, saw the possibility of American involvement in World War II, and he wrote an 11 item memorandum regarding NACA research facility personnel and their military obligations. In this memorandum he noted that many of the engineers at the research laboratories would be called to active duty or would voluntarily enlist, thus reducing the number of men at these facilities. He further noted that in the event of war, there would need to be a rapid acceleration of expansion of facilities and personnel. When the United States entered World War II many of Lewis's predictions were borne out. There was a pressing need to expand the LRC research facility and its personnel. Recruitment brochures and announcements were quickly printed and dispersed throughout the country. An employment bulletin for 1943 called "NACA" describes the routes and means of transportation for those interested in employment at LRC. This bulletin noted that

the only land connection Langley had to the rest of the state was a narrow neck of land north of Williamsburg, an area still referred to as Northern Neck. It points out the railroad routes and the need to take a ferry to Old Point Comfort (now included in the city of Hampton) except for the direct rail line from Richmond, Virginia. The bulletin further noted that two steamship lines, the Norfolk and Washington and the Baltimore, also provided access to Hampton. The recruitment brochures, one actively recruiting engineering graduates and issued in 1943, describes the wonderful career opportunities in the field of aerodynamics, the pleasant living facilities, and the fact that many women were now employed at LRC as well as the various recreational opportunities provided. Of the ten photographs included in this brochure, two are of women's housing while three show women engaging in recreational activities. The remainder are of women and men working together. Included earlier in the section about the arrival of the women at Langley was that several first heard of the computing positions through bulletins sent to their colleges.

Another recruitment brochure describes the exciting new field of aerodynamics as well as a description of the types of research being conducted at LRC. It should be kept in

mind that degrees in aerodynamic engineering had not yet been developed in most college curricula; however, many colleges offered degrees in engineering with a specialization in aeronautics. Ralph Beilat graduated from Rensselaer Polytechnic Institute in 1941 with a degree in aeronautical engineering noting that Rensselaer was among the first to offer this degree, which he attributes to the fact that the engineering department was headed by a Dr. Paul Hemke, a physicist who had been at NACA in the early 1920s. Lewis had also recommended that in the event of war, an agreement be reached with the military to exempt NACA personnel from war duty and that an estimate of the increase in personnel needed be made. Lewis strongly recommended that NACA and the military be kept separate in order not to develop a military rank order in NACA in the event of war. Bielat recalls that many college athletes took advantage of this means to avoid the draft and were as quick to leave after the war ended. He relates he was sent to Richmond, the capital of Virginia, inducted into the Air Corps Enlisted Reserve, and returned to NACA. He further notes that if you left NACA, you were put back on the active list. Axel Mattson followed the same procedure and states this policy was necessary because aeronautical engineers were at a premium.



With the exception of Vera Huckel, who came in 1939, and Pearl Young who worked at LRC from 1922 until she transferred to the Lewis research facility in 1943 and mentioned earlier, women generally were not recruited prior to World War II. The few women who did work there before the war were primarily in the traditional jobs of secretaries and clerks. By 1942 the success of using women as human computers at LRC prompted the encouragement of installing women computer groups at other facilities. A report written at that time cites that the recruitment of women for this work was desirable not only to fill the void left by the men who had gone off to war and the expanding need for personnel, but also because studies had shown that women scored higher than men on clerical aptitude tests even compared to men scoring well on engineering tests.

As related earlier, prior to the employment of women the engineers had had to perform all of the calculations generated by their research. Because women were paid less for these jobs, this report also stated that their employment would also be economically advantageous and solve the personnel shortage. Included in the report was the notation that because of some opposition to the employment of women in this previous all-male operation, the women had

been placed in a pool not dissimilar to a typing pool; however as opposition decreased, LRC became able to assign groups of women to each research Section. This was also pointed out to be economical because women could be assigned as supervisors for each group which would reduce the time and amount of training required for each computer that had been necessary when they were limited to one pool performing all the needed calculations.

The required qualifications for computers was stated as not being very rigid; these jobs would be filled through Civil Service examination or by level of education and experience. It was noted, however, that as early as 1942 both the female supervisors and computers were mostly college graduates with degrees in science and mathematics; most had formerly taught mathematics in schools. The women's average age was between 21 and 30, and there was no restriction on marital status. By then, several of the computers had already married LRC engineers. For example, Rowena Daniel married John Becker, Sadie Miller married Harvey Hubbard, and Ann Merfeld married Axel Mattson.

Part of the opposition to the employment of human computers was the cost of purchasing more calculating machines and other necessary equipment. These calculating machines were

hardly more than upgraded adding machines and according to Helen Willey, were the size of shoe boxes. The computers relate that they discovered how to do more complex calculations on these machines by finding ways to get them to perform subtraction, multiplication, division, and square roots. The average cost of these machines was more than \$500, and each head computer was allowed to select the model she wanted in her computing pool. The women note that each computer had a favorite brand of calculating machine and would often refuse to work on another brand. Some preferred the Marchand, while others favored the Friden machine; each recalls which was their favorite. Another piece of equipment used by the computers was a comptometer with only one brand purchased.

Additional equipment provided were 20-inch slide rules (some Sections were limited to one while others had several), tracing tables, sets of logarithmic and trigonometric tables, along with other assorted calculating aids. Aside from the initial cost of the calculators, the next largest expense was salaries; however, both officials and engineers agreed this expense was justified by the savings in time and labor on the part of the engineers and their assistants, called junior engineers. One engineer stated at the time that calculations that had previously taken him a whole day

were now performed in a matter of a few hours by the computers and far more than one research data set was calculated in a day. The computers were housed in whatever space was available, and after being broken down into specialized groups, were simply given a portion of an available room. The computers recall that while some of these makeshift arrangements were pleasant, others were not. For example, some of the computers like Rowena Becker found themselves working in what had formerly been a porch with a wall of windows which afforded them a wonderful view of the Back River; others recall working in hallways and drafty or noisy areas.

Part of the recruitment strategy was to reduce the opposition to employing women by first screening them. Elton W. Miller, Chief of the Aeronautics Division at LRC, devised a plan in which the women would first be evaluated for suitability before placing them in the research Sections with the men. A classroom/workshop was set up in a storage area of one of the tunnels where the women could be trained for two weeks and then evaluated. The women accepted for preliminary training were selected based on personal interviews that measured attitude, appearance, willingness to work at night (night shifts had been added to increase

production), and educational background and experience. It is noteworthy that the order in which the qualifications were listed, attitude and appearance appearing first, is in keeping with the computers having mentioned earlier that attractive women were more likely to be hired. It was also felt at the time that the women would perform at higher levels if their part in the war effort was stressed.

During this two-week training and screening period, the women were instructed in reading vernier scales, manometers, and balancing scales as well as interpolating data from the types of calculations required in each research Section. This accelerated two-week course proved to be successful. Once assigned to Sections, the longer women worked as computers, the more skilled and valuable they became, thus their retention became an important goal. The only unfavorable note about the computers was that married computers were more reluctant to work the night shift citing their husbands' opposition to night work. Therefore, it was decided to gear the recruitment to unmarried women as much as possible in order to alleviate this problem. The women are reported to have worked as well under pressure as the men, and most received high to excellent report ratings.

Although the drop-out/dismissal rate during training was below 20 percent, it was felt necessary to continue the screening program. Pay increases were recommended for the "better" computers.

### HOUSING

Because of the war and the limited number of residential homes in Hampton, housing the increased personnel at Langley was a problem. This serious shortage of available housing was addressed in several ways: The Federal Housing Authority funded several housing projects, and because of the war, many of the new personnel at Langley were able to rent rooms in private homes with families that felt it was their patriotic duty to assist in the housing shortage. As described earlier, some of the women were able to rent rooms with professional families when they first arrived. Another example is when Ann Merfeld, who later married Axel Mattson, arrived in Hampton, she was unsure of where she could stay. A woman whom she later found out was the wife of Dr. Elton Miller, Head of the Aerodynamics Division, invited her to stay with them until she found suitable quarters.

One of the first housing projects, built in 1943 at a cost of a quarter of a million dollars, was a women's dormitory named Anne Wythe Hall with 372 units in the Wythe section of Hampton. Now called Kecoughtan Court Apartments and within a block of this author's home, it is still in use. The site in Wythe for what was described then as temporary housing was selected for its closeness to trolley lines and the presence of a shopping center. The women, however, describe it a a remote area with a very limited number of restaurants available to them. Anne Wythe Hall housed 368 single women in three dormitories and also included a community building and an infirmary. There was a resident manager as well as a house mother assigned to each dormitory and an I.D. was necessary to gain admittance after 11 P.M. Rent was set at \$5.00 a week for a single room and \$3.00 for a double room.

Two additional projects were built and were named Cavalier Court and Copeland Park. These housing units were small single family homes, and although these homes were also available to Langley Air Force personnel, LRC personnel had first claim on them. The larger of these two housing projects, Copeland Park, had 5,000 units while Cavalier Court provided 372 units. The Cavalier Court houses were designed with two bedrooms, one bath, a combined kitchen-dinette area, and a living room. Each home was coal heated

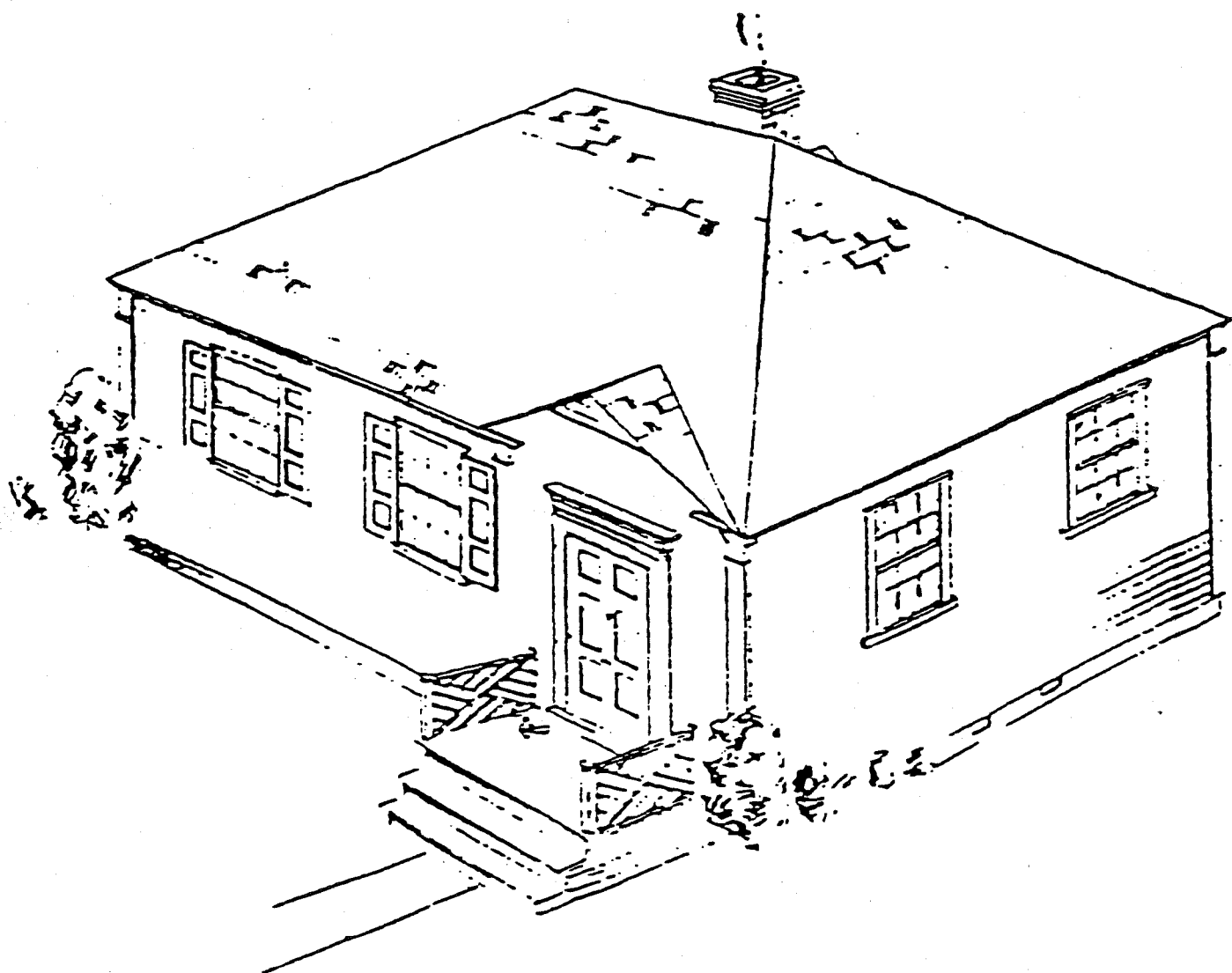
and came with a coal stove installed. To avoid the monotony of sameness, eight different exterior colors were used and several minor variations in the basic style were also featured. Figure 5. is an illustration of a Cavalier home.

Ralph Bielat reports that of the 42 graduates in his class, he was one of the seven who came to NACA, and he shared an apartment in Stuart Gardens (another of the NACA projects) with three of these seven. Mattson first lived with a family in Newport News, later moving to a private home that rented rooms to the young engineers at NACA. It was here they began to call wherever they lived the X Club as did many of the other young engineers.

#### TRANSPORTATION

Although the housing sites selected took into consideration the availability of transportation, it continued to present problems primarily because of the shortage of gasoline. This problem was partly solved by the use of public transportation and partly by the use of "riding combinations" in which anyone owning a car was asked to pick up other employees on their way to and from work. This is similar to the "share-a-ride" concept presently being





CAVALIER COURT HOUSING UNIT

Figure 5.

promoted to reduce pollution. A riding combination cost each passenger one dollar a week, and there was no discrimination between sexes or among job ranks; engineers, computers, and other personnel shared these rides. Marie Burcher recalls using a riding combination for transportation to and from work even after she married. She states that an engineer owned the car in her riding combination and that her husband always felt that this engineer drove too fast. She says her husband was particularly upset about her riding with him after she became pregnant because she would also be jostled around too much.

Ralph Bielat and Axel Mattson described their experiences in the riding combinations. Bielat remembers that one of the women he picked up each day, Rosellen Hoffman, was a particularly pretty woman who later married an engineer at the Newport News Shipyard while another woman named Janet Broad had a great sense of humor and entertained them during these rides back and forth to work each day. Mattson relates that he later rented an apartment in the waterfront home of Fred Cox, an old Virginia riverboat pilot, and he would pick up Rowena Daniel (later Becker), who lived close by, in his small boat and they would then transfer to his car at the dock. He was particularly proud of the car he drove at the time, a Buick Roadmaster.

An in-house newsletter entitled "LMAL Bulletin" noted that there was a shortage of riding combinations for those who worked nights, and also urged anyone who owned a car but not using a riding combination to start one. Interestingly, for personnel who worked nights the most difficult area to get to was Copeland Park. A further request was made to use riding combinations for holiday traveling, especially at Christmas. Everyone who was planning a holiday trip was asked to post their name, destination, and departure and return dates so that anyone going in the same direction could share the trip.

#### RECREATION

By 1944, with personnel at its highest peak (3,822), there was a growing concern for providing recreational activities for this largely young group. Still known as LMAL at the time, the administration provided land to build a recreational center. Since various personnel had organized small activities groups, they were asked to form a committee to set up a permanent recreation council. Six months later the Federal Works Agency provided a grant of \$111,330 to

build a recreation center. In 1946 a newer and larger center was dedicated and opened. Personnel were excused from their jobs to attend the dedication ceremony, which was followed by sports exhibitions. The Center was open six days a week until 10:30 at night and could be used to stage Section parties.

Prior to these facilities being built, it was necessary for personnel to provide their own entertainment. One form of entertainment that had begun in the early 1920s later grew into the first organized group entertainment. With less than 100 employees, a common practice was to welcome a new employee with a little hazing in the form of itching powder or a zap with a booster magneto to determine if he was going to "fit in". This initiation rite was referred to as the Noble Order of the Green Cow, a name some say was borrowed from someone's alma mater, while others say the name was selected because they felt it would reflect how they would feel the morning after a party. It was also not uncommon for someone to be initiated more than once. Helen Willey relates the story of how Ralph Bielat had failed an initiation rite at NACA by not being able to ride a bicycle across the sea wall in from of the 8-foot tunnel. She said the proof of his failure is his tie clip which still lies somewhere at the

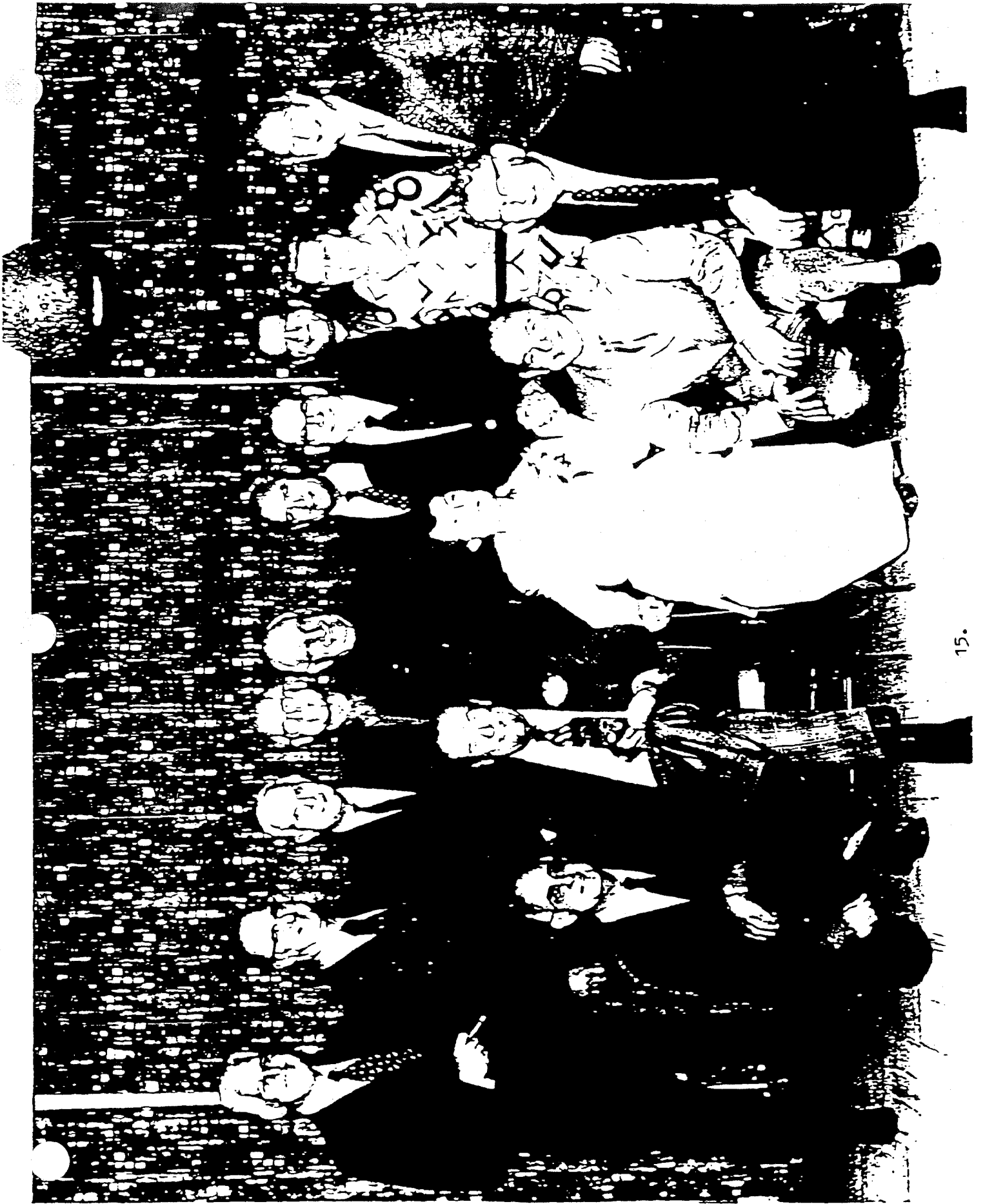
bottom of the water. Bielat's explanation of this event is that the initiation took place on the first day after his return to NACA following hospitalization resulting from an automobile accident. In this accident, Shipyard employees were racing to get their dates home in order to report for work and hit the car he was driving, therefore, his unsteadiness on the bicycle was not due to his lack of skill, but to his recuperative stage.

When a new Service building opened and because a new building was always a cause for celebration, a dance was organized. This dance was a success, and so with a rapidly increasing number of new people, dances began to be scheduled at the Hampton Armory and the Noble Order of the Green Cow was transferred to these dances.

A planning committee was organized, an annual membership fee of \$3.50 was set, and dances were held once a month. It was decided that each dance would open with a ceremonial promenade headed by the Green Cow. A two-man costume was made, and it is reported that the Green Cow did not always make a graceful or coordinated entrance. There were often themes for the dances; a celebration of the Gay 90s held in 1943 called for appropriate costumes and the arrival in a

mode associated with the horse and buggy days. This latter requirement was due to the restricted use of gasoline. By 1942 women could also be nominated for the four positions on the executive committee. The success of the Green Cow is evident by the 472 nominations cast for 22 people in the election for 1943.

Another site used for social gatherings was property that had been purchased privately by 10 Langley officials who each put up \$1,000. According to Bielat, a typical party would be a cookout. They would dig a pit in which Dolph Henry, a Langley cafeteria chef, would bury and bake beans. Over the pit would be boards on which they hung chicken to cook in the reflective heat of the pit. This method had been borrowed from the locals who cooked Shad using this method, hence, they were called Shad boards. By 1948 most of the original owners of this property had left, and it was purchased by Mattson and remained the site for many parties. A few years ago the house burned down and Mattson relates that almost all of the memorabilia from the early days was lost along with their private belongings. He and Ann rebuilt a home on the same site where they still live.



John Stack, the Assistant Director at Langley and discussed later, had appointed Bielat a committee of one to organize other social activities. For one party, Bielat arranged a day of golfing at a nearby course, which led to the idea of forming clubs. The women organized "Gigs" (Girls in Government Service), a choir, a drama club, and sport clubs. The women are reported to have had a very good basketball team. The men organized a variety of clubs and inter-departmental football teams, which often scheduled five games a week. There also were hobby and craft clubs for both the women and the men. As noted earlier, there were several outstanding college athletes at Langley at this time, and the basketball coach at the University of Virginia challenged them to a game which the Langley players won.

A recreational facility was later built at Langley and taken over by the Morale Activities Association. It was run on a voluntary basis and they drew up a charter. They needed a fund raiser to support their athletic teams and the small charge for dances did not bring in enough money. Someone suggested they should purchase Bingo game sets which cost twenty-nine dollars and included both the Bingo cards and



prizes. They charged players one dollar for ten games and the first night made 200 dollars; a profit of one hundred and seventy-one dollars. They made even more money when they added beverages for sale, and at the end of the first year they realized a profit of eight thousand dollars, more than enough to cover the expenses of the athletic teams.

There were also social activities in Hampton that were available to them. The USO offered movies, boxing instructions, and dances with some of the dances scheduled from midnight to 3:00 A.M. for those on the night shift. Another popular pastime was the Hampton Little Theater. Season tickets for the theater were one dollar for seven different performances and there were no single performance tickets. Taking a date to a movie theater or going on a picnic were other social activities, but as pointed out by Bielat, while you went on picnics with a group, you went alone with your date to the movies. He also shared that if you liked a woman and wanted to ask her out on a date, you telephoned her at home, never asking for a date while at work.

Throughout the interviews the computers often mentioned the engineers they worked with and the admiration they had for

them. For example, Helen Willey relates "I worked for Dick Whitcomb, Eugene Draley, Axel Mattson, and John Stack as my immediate superiors and you couldn't do better than that"; however, the engineer's name mentioned most often was that of John Stack. Stack began his career in 1928 when there were less than 200 employed at LRC. By 1939 he was in charge of the eight-foot High-Speed wind tunnel, and in 1947 was made the Assistant Director of Langley. Stack was later appointed Director of Aeronautical Research at NASA headquarters in Washington, D.C. in 1961. He is credited with having acquired after World War II two of the most knowledgeable aeronautical scientists, Antonio Ferri of Italy and Adolf Busemann of Germany. Noted earlier, Stack was the recipient of two Collier trophies (1947, 1951), numerous foreign awards, and in 1962, the Wright Brothers Memorial Trophy.

Much has been written about Stack's career, but the computers' memories of him have not been told before. Margaret Block recalls him putting his foot up on Millie Woodling's desk waiting for her to finish the calculations he had given her, and Rowena Becker notes that Stack would pull a chair right up to her desk and ask her to work fast because he was in a hurry. Emma Jean Landrum recalls that



even after Stack was made Assistant Director, he still wanted his work done by her computers and would frequently hand carry the work over to her. Since he was always in a hurry, Landrum states he preferred to come over to her Section rather than wait until results could be brought to him. She describes him as "a colorful character who didn't suffer fools gladly; if he like you he treated you well." Axel Mattson's assessment of Stack was "If you got along with him you enjoyed the devil out of him; if you didn't, you thought you were working for the devil himself". Helen Johnson adds that all the engineers as well as Stack "wanted everything yesterday."

While all of the computers who worked with him report "The air was blue with Stack's picturesque language, his remarks were always directed at situations, not people." He was noted for his storytelling, and Marie Burcher recalls that his chair fell over backwards in the middle of a story, he righted the chair, and finished the story. Burcher went on to relate that when Stack heard that a man's wife had just had a baby and he had had to bring his two other children to work with him and had left them in the car outside, Stack sent the man and his children home, admonishing him not to return until his wife got home from the hospital. In a

similar vein, Helen Willey relates that at the time she was expecting her first child she also found out her mother had terminal cancer so she and her husband wanted to move to her parent's home to care for her mother. Unsure of what to do, she asked Stack for advice. He told her to care for her mother and to not worry about her job; it would be there when she got back. As a final note on John Stack, Willey recalled that he once sat on her desk and said "I don't understand it, Martha doesn't know what she wants to do with her life." Helen Willey smiled and said, "Martha was his daughter who was a high school freshman at the time." It is reported that Martha became a schoolteacher.

Today, professional women often have difficulty getting maternity and family leave benefits from employers, but the human computers did not experience these difficulties. Margaret Block, who did not return to work after the birth of her first child, notes that accrued sick time could be used for maternity leave. Although it was the social custom at the time for women to leave their jobs when expecting their first child and to not return to work, NACA generally provided them with this option. Marie Burcher makes the interesting comment that everyone was always too polite to mention that a woman was pregnant, but would begin treating

the woman with extra care. After working at Langley for three years, Vivian Adair was temporarily assigned to NACA Headquarters in Washington, D.C. in order to receive medical treatment for her condition. It was her mother who had read about a physician in D.C. who was a specialist in nerve deterioration and had written to him to ask if he could help her daughter. Adair says it was this kind of cooperation and consideration that made it possible for her to receive this treatment.

It was mentioned earlier that Helen Willey, who had accrued enough sick and annual leave time to remain off the job for six months with the assurance her job would be secure, further notes that she was also able to return to work after the birth of each of her two children. Part of the reason Willey could return to work after each birth was because of the help and cooperation she received from her husband. After the birth of her first child, she hired a woman to come into her home to care for the child so she could return to work. She relates she is still in contact with this woman who is now quite elderly. Later, when her children reached school age, her husband, who was a schoolteacher, arrived home at the same hour they did and took over their care. Willey states that it was not unusual when she arrived home

later in the day to be told by her husband to "Take the kids out while I make dinner", which she always promptly did. Her father, a retired minister and a widower, often commented that Willey's husband put him to shame as a housekeeper and cook.

Mary Jackson recalls that her husband did all of the grocery shopping and cooking for the family; she never had to concern herself with these chores. Recently widowed, she shared that following church services on a recent Sunday, a fellow parishioner asked her if she was weeping because she had lost her husband or because she had to go home and cook for herself.

## SEXISM

The human computers all deny there was any evidence of sexism during their years at NACA, and that they were always treated with respect and made to feel part of the team, especially during the war years. It should be kept in mind, however, that what would constitute sexism today was viewed differently during the period in which these women worked. In fact, one computer related an unprintable example of sexism which even now she fails to recognize as such. The only reference these women make to gender differences is in reporting that LRC was a "man's world" and that there was "not much opportunity or encouragement for female advancement." Several reported that it was "who you worked for and encouraged you (the engineer) that determined whether you got an opportunity for advancement." The women at LRC were always referred to as "girls" even in official reports, a term unacceptable today. During the interviews the computers themselves spoke of the "girls in their Sections."

One example of aerodynamics being a man's world is found in the selection of test pilots. Despite the fact that many



women including Americans Bessie Coleman, Ruth Elder, Matilde Moisant, and Pheobe Omlie, and British pilots Amy Johnson and Beryl Markham were licensed and experienced pilots, they were never considered, while Germany, as early as 1934, used Hannah Reitsch as a test pilot for their newly developed gliders and research into V-1 suicide rocket-propelled planes. Despite the war, Russia held a state funeral in the Kremlin for Marina Raskova in recognition of her heroic record as a fighter pilot (Golemba, 1992). Even the best known American woman pilot, Amelia Earhart, was invited only as a guest to LRC in 1928. It was not until 1960 that a woman, Jeraldyn Cobb, was allowed to take the physical examination for the astronaut program, but she was never selected. It was 1978 before six women were finally selected for the astronaut program with Sally Ride becoming the first female astronaut. With the exception of Pearl Young, and to an extent, Vera Huckel, a Junior Engineer, there were also no women aeronautical engineers.

Like other industries during World War II in which efforts were made to glamorize or feminize the jobs women were doing, LRC followed suit. The following two illustrations taken from the in-house newsletters from the early 1940s are

examples of the feminization of women's jobs in aeronautical research:

"Safety Cap- New LMAL Millinery Note"  
Women workers blossom out in their latest style safety caps...not only flattering but comfortable...worn on the back of the head the effect is highly decorative but extremely dangerous (for safety reasons) and, acceptance of the hat by the women employees was described as gratifying by the Safety Board.



Figure 5.

Figure 6. depicts women's work apparel in a fashion show with the women modeling and showing acceptance of the approved work outfits.

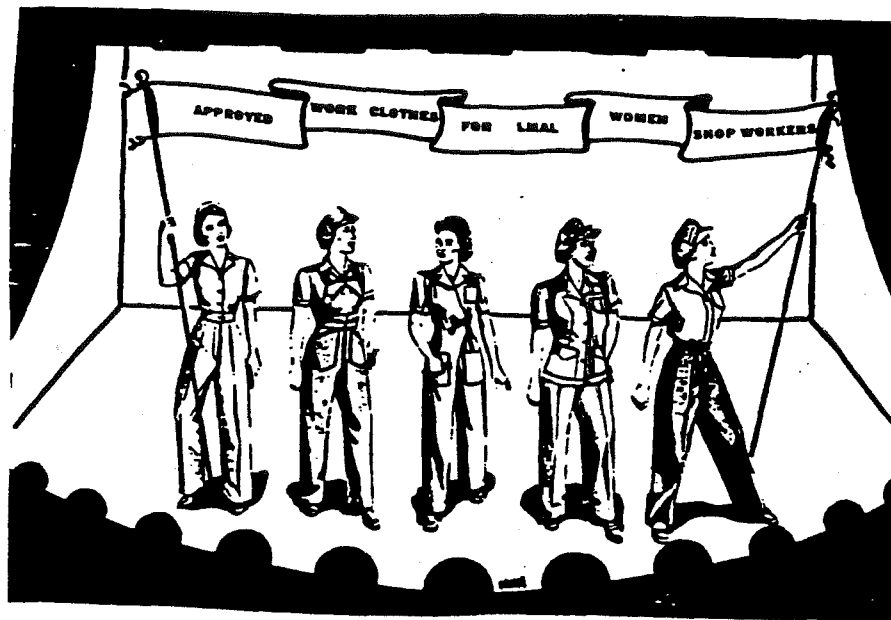
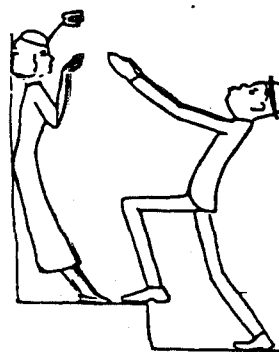


Figure 6.

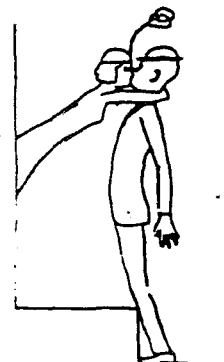
The following two drawings reflect a sexist attitude by giving an aeronautical interpretation to dating and female anatomy:



Figure 7.



Resistance on the Step



Over the Bump

Figure 8.

The most blatant example of sexism is found in this provocative drawing and description. Entitled "Technical Notes", it describes a research investigation of "high and low powered models tested and untested at the NACA". It states:

These models were characterized by fairly forward location of their c.g. {center of gravity}, low aspect ratio, and definite stalling characteristics...Leap Year was taken to be a constant during the investigation...the curve is certainly a mean curve".

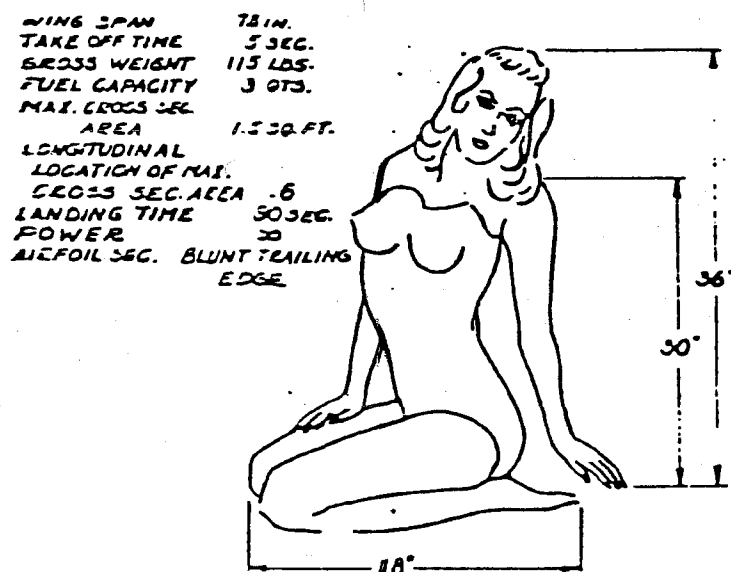


Figure 9.

The article concludes by noting that:

Since the new replacement program is opening new horizons for our models to conquer, it is suggested that Congress appropriate adequate appropriations to facilitate future investigations of this nature.

The article also provided the information that there were 955 women employed with 453 of them single. The following appeared in the in-house newsletter called *Air Scoop* (1945) and portrays the women as child-like:

When the first sizable groups of women came to work here...hard-bitten males made the usual dismal predictions...but now wonder (secretly of course) how the laboratory ever got along without its distaff side. Women are now practically one third of the staff. They're the cute youngsters in baggy sweaters and bobby socks...The laboratory has girls in its so-called glamour jobs...They're the engineers, -aeronautical, mechanical, and electrical, -the artists, draftmen, laboratory technicians...the list is endless. And it includes an impressive number of girls whose pert figures and pretty faces belie the implications of their "Mathematician" rating.

It concluded with:

But one thing binds them together. You can see it in their eyes when they pass Old Glory flying proudly over the field...So we say, here's to the ladies! God bless them.

A January, 1945 issue of *Air Scoop* entitled "Second Epistle to the NACAites" and stated as a prayer, admonished the women not to dress provocatively nor to take the remarks by the engineers to heart:

And if thou art female, take care that thou cometh not to work in fine raiment lest thou stand out like a sore thumb. Put aside thy silken clothes, thy dainty frocks, thy ankle-strap slippers. And attire thyself in a sweater of mammoth size together with a skirt that reacheth not the knees, and around thy throat drape a rope of fake pearls.

And woe unto thee if they shall make thee a computer. For the Project Engineer will take credit for whatsoever thou doeth that is clever and full of glory. But if he slippeth up, and maketh a wrong calculation, or pulleth a boner of any kind whatsoever, he shall lay the mistake at thy door when he is called to account and he shall say, "What can you expect from girl computers anyway".

These Figures and quotes from *Air Scoop* reveal the attitudes of men toward women during this time frame. When women took over jobs formerly done by males, the jobs were glamorized and feminized (reduced in value). There was much emphasis on the physical attributes of females, and women were described as being child-like. The admonition, especially in the form of a prayer, strongly implies that it is women who entice men, and that the computers should forgive (a virtue) criticisms made by the engineers.

## VERA HUCKEL AND THE SONIC BOOM STUDIES

As noted earlier, Vera Huckel first worked for the famous aeronautical engineer, Theodore Theodorsen. His admiration for Huckel is reflected in his asking her to accompany him when he went to South America to do studies. His letters of recommendation for her also reflect his admiration and confidence in her ability. In one letter for a promotion for her, he described her as "possessing unusual ability to keep the most perplexing problems running smoothly and efficiently" and in another, "(her) unusual ability to organize and perform complex and lengthy calculation is well recognized by all members of the division." When asked which job she enjoyed most in her career, Huckel states that the most exciting and satisfying work she ever did was in the early 1960s when she did field work in the California and Nevada desert areas measuring decibel levels of sonic boom. She recalls making 10 or more trips to the desert. The desert was selected as the best site for conducting much of the sonic boom research because of its remoteness from population centers, more suitable weather from an aircraft operational view, and fewer disturbances and background noise from other activities. Most of the studies were done

early in the morning under more stable atmospheric conditions. In the afternoon, the desert floor would heat up causing the lower layers of the atmosphere to become unstable and more turbulent, which would cause data collection problems.

While Huckel sometimes brought along a few other computers with her on these desert studies, she most often was the sole woman on them. She relates that on one of the earliest projects she and a secretary were the only women, and women as team members was most unusual. During this project they were to be based at Edwards Air Force base in California and housed in the Temporary Officers' Quarters (TOQ). Base personnel were unsure what to do about assigning rooms to the women, but once the billeting officer realized that Huckel had a government Civil Service rating equivalent to a one-star General, he assigned the women adjoining rooms commensurate to Huckel's rating. When the research group arrived in the dining hall in the early morning, the military officers looked shocked that these NASA scientists were allowed to bring along "their own women".

In order to appreciate the pioneer research done in sonic boom starting in the mid-1950s, an explanation of sonic boom and a description of the research conditions is given here.



This information was provided by Harvey Hubbard and Domenic Maglieri, the two most noted sonic boom experts at the time. Hubbard was Branch Chief in charge of the sonic boom studies, and Maglieri, whom Hubbard describes as "my right-hand man", was one of the major engineers who conducted the field tests. Hubbard estimates that the sonic boom studies during those years cost approximately 50 million dollars, involved about 100 people at the research sites as well as additional people working on the data at NASA-Langley, and Air Force planes and pilots.

The easiest analogy of sonic boom was provided by Hubbard who compared it to the "crack of a bullet." The "crack" is the sound emitted by the bullet as it travels faster than the speed of sound. There are in fact two cracks emitted, but are so close together they are heard by the human ear as a single crack. Since more aircraft were beginning to travel at speeds of Mach I and higher and emitting sonic booms that were complained about by the public, there was need for research into this phenomenon.

A sonic boom occurs when an aircraft is flying faster than the speed of sound, disturbing the air through which it is traveling and creating shock waves which emanate from the

surfaces of the aircraft. The sonic booms of interest in these studies, the ones that travel toward the ground, are those which come from the lower surfaces of the aircraft. The waves coming from the front of the aircraft are called bow-waves and those from the rear, tail waves. As these bow and tail waves descend toward the earth, each coalesces into a single wave. These are the two waves (sonic booms) that hit the earth's surface and are audible. When electronically recorded, they have the configuration of the letter N and, therefore, referred to as the signature or N-wave. An interesting note is that the sonic booms last less than a full second.

The factors correlated with the intensity of the booms are the size and weight of the aircraft, the altitude at which it is flying, and its speed. Altitude especially affects whether or not the sonic boom is heard at ground level; the higher the altitude, the more time and distance for the waves to dissipate, so the less bothersome the sound. However, because of the variables of aircraft size, shape, and speed as well as atmospheric conditions, no "ideal N-wave" (acceptable noise level) has yet been established. Another wave of concern is the focus boom, which occurs when an aircraft accelerates from subsonic to supersonic speed.

creating more intense shock waves. For the purposes of the research done during the early parts of the decades 1950 through 1970, all aircraft flew in a linear flight track at a steady speed (non-acceleration) in order to establish a data base. The research involved the use of multiple types of aircraft at various speeds and altitudes.

The primary research purpose of these studies was to generate a data base on sonic boom that would provide greater insight into its generation, propagation, prediction, and effects on people, animals, and structures with this knowledge aimed at developing an economically and environmentally acceptable supersonic transport (SST) that would have a low sonic boom. A large scale sonic boom study was conducted over a six month period in 1964 by the Federal Aeronautics Administration (FAA), supported by the Air Force and NASA, involved the sonic booming of Oklahoma City four times each day under controlled aircraft operating conditions and observing the effects of these sonic booms on humans. Maglieri and Huckel were involved in this early study and although Huckel was not on-site, the data was sent to her daily at Langley where she performed the data reduction and analyses. Figure 11. is an example of the work she did. While the U.S. National SST program was eventually

abandoned, Russia built a supersonic cargo-transport, the Tu-144, in 1975 (no longer in service) and England and France built the Concorde in 1976. An interesting note is that the Concorde waits until it is over the Atlantic Ocean to accelerate in order to reduce the subsonic to supersonic speed annoyance factor.

There were other questions regarding sonic boom effects as well as the development of the SST. One of particular interest to the Air Force who at the time were developing a supersonic tactical fighter plane, the TFX, which could be used by both the Air Force and the Navy. Since this aircraft was to be capable of supersonic speeds at very low altitudes or "on-deck", it was of interest to determine if its very intense sonic boom could be used as a combat weapon to destroy ground structures, ground-launched missiles, radar equipment, and even clear mine fields. A sonic boom test program was conducted at Nellis Air Force base by the Air Force and NASA to determine the effects of intense booms on ground structures and equipment. As a matter of interest, the TFX finally evolved into the F-111. Huckel was directly involved in these tests and played a very important role in the measurement, analyses, and documentation of the test findings. The results showed that this destructive potential was not possible.





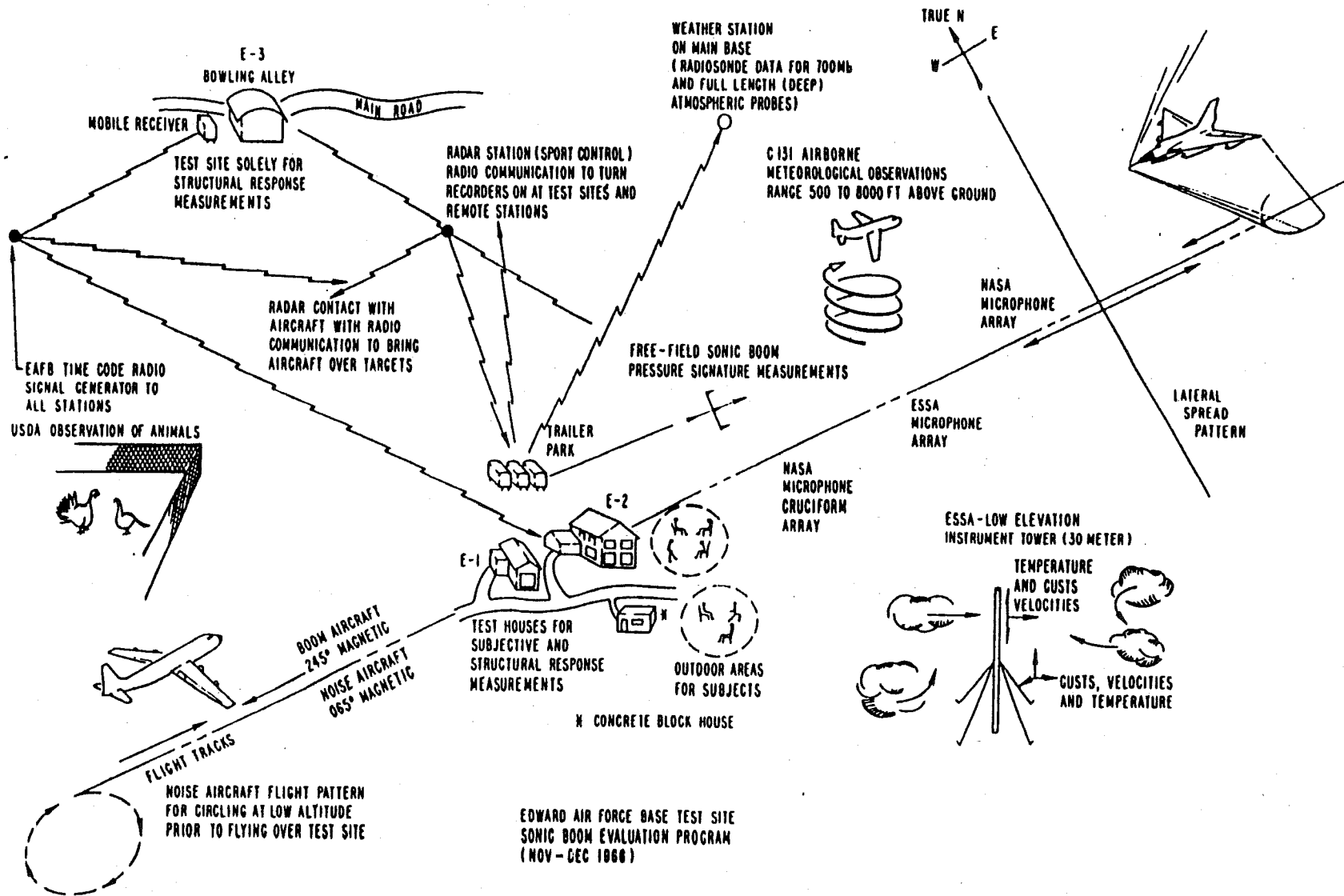
The sonic boom research projects described here involved numerous government agencies including NASA, the Air Force, and the FAA as well as private industry, and universities. Most of the investigations were directed toward increasing understanding relative to sonic boom generation, propagation, and prediction. To further understand the complexity of the research done by Maglieri, Huckel and the rest of the teams in the sonic boom tests, a description of the set-up for this pioneer work needs to be described. Each research team involved would arrive very early in the morning to run the tests. These tests needed to be run in the morning because in the afternoon, the desert floor would heat up and cause the lower layers of the atmosphere to become unstable and more turbulent, which would cause the sonic boom N-wave signature to become distorted. The teams would set up and run tests, collect data, and collate their findings with the sonic boom measurements done by NASA. The NASA team was responsible for directing these multiple tests, which involved a great wealth of raw data that not only had to be assembled, tabulated, plotted, and analyzed, but also had to be correlated. All of this raw data would be given to Huckel, who would perform these operations (on some projects, the volume of data was so great that she brought along computer technicians to assist her.)

Both Hubbard and Maglieri describe Huckel as being the "linch-pin" in these projects. Maglieri recalls that if Huckel did not receive the data when it was due (it was reduced, tabulated, plotted, and analyzed daily), she would seek out the tardy engineers and remind them that "while they had their work to do, so did she." He also states that she frequently was already at the test site and working when the rest of the team arrived early in the morning, usually at dawn.

Huckel was also responsible for providing copies of all the data (boom signatures, aircraft operating conditions, weather and radar tracking) available to the other government agencies, contractors, and universities in these joint programs. Figure 12. shows the physical layout of one of the test sites. It is mentioned here that Huckel was later involved in the classified sonic boom study on the SR-71 aircraft, known as the Blackbird, and continued her involvement in this kind of research into the Space Age by being directly involved in the measurement and analysis of the Apollo and Saturn-5 space shuttles ascent and reentry sonic booms. Figure 13. is one of the awards she received.

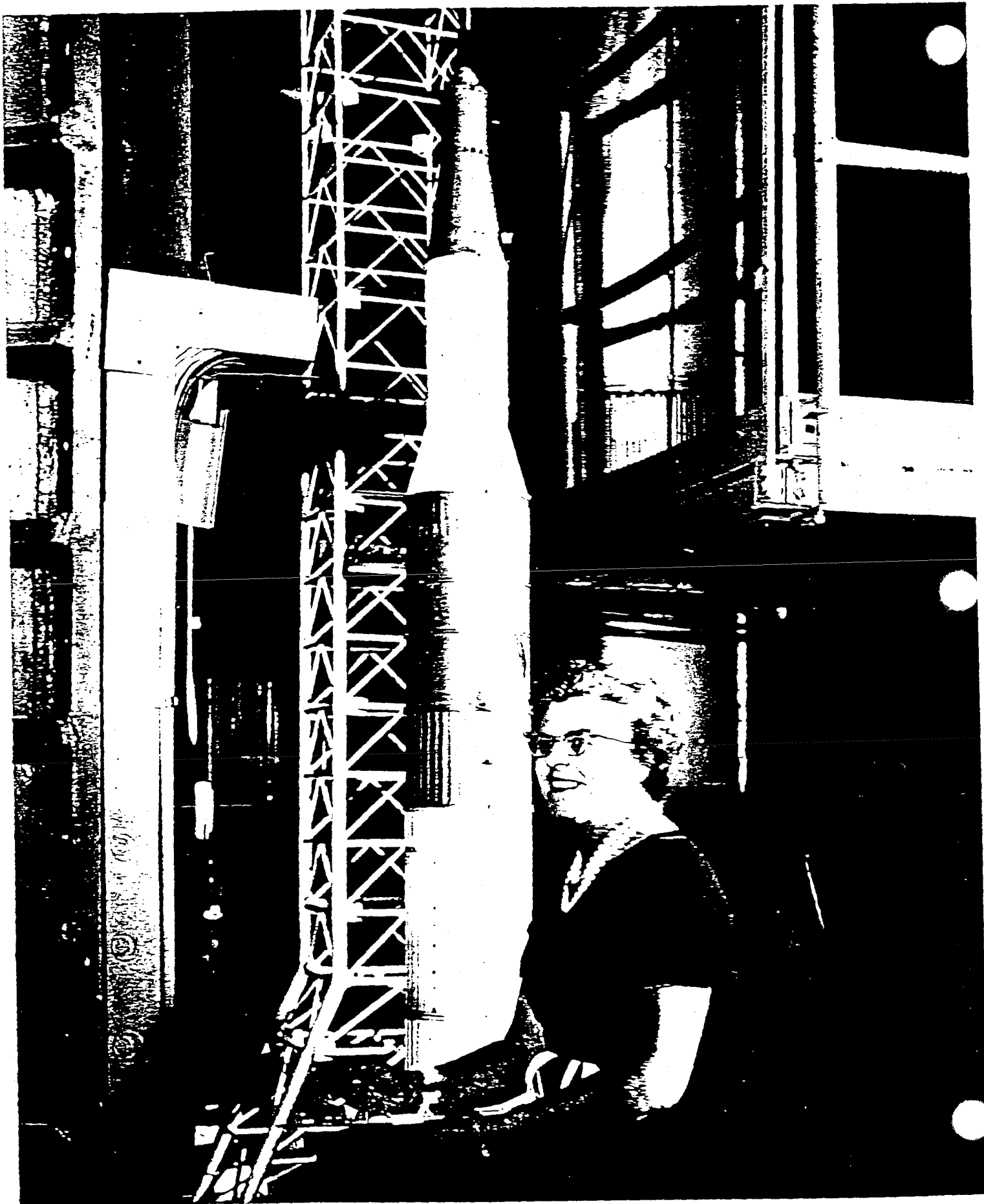
When asked about the sonic boom projects, conditions, and recreational opportunities in the desert, Huckel said that





SKETCH OF ACTIVITIES DURING SONIC BOOM TESTING (Arrows indicate flight tracks used for tests, except for 4 XB-70 flights flown offset 13 statute miles and certain B-58 flights flown offset 5 statute miles.)

Figure 11.



The National Aeronautics and Space Administration  
presents the  
**A**pollo **A**chievement **A**ward  
to

VERA HUCKEL

In appreciation of dedicated service to the nation as a member of the team which has advanced the nation's capabilities in aeronautics and space and demonstrated them in many outstanding accomplishments culminating in Apollo 11's successful achievement of man's first landing on the moon, July 20, 1969.



Signed at Washington, D.C.

*W. L. Rinehart*  
ADMINISTRATOR, NASA

while these projects were the most exciting she had ever worked on, the conditions were less than ideal. The desert was hot, the days long, and the research facilities fairly primitive and "certainly not air-conditioned." She would return to NASA between projects, but when involved in them, she stayed either at Edwards or Nellis Air Force bases or at nearby motels, depending on the project and its location. As for recreation, Huckel says there was virtually no time for any since they worked long days (the work did not end when they left the research site) and often worked weekends. She also reports that little recreation was offered in the remote areas where they were. She would occasionally go to Los Angeles to visit old friends or the entire team would go to Las Vegas to gamble. Huckel smiled when she shared that while she was single, most of the engineers were married and often had limited amounts of money, so they would borrow money from her in Las Vegas; they always paid her back.

The studies done on human response involved stationing people both indoors and outdoors engaging them in a variety of activities, recording their opinions by questionnaires, and observing their reactions to the sonic booms. Measurements of the response of structures to sonic booms, especially windows, were also included. The results

demonstrated that while the sonic boom was less intense inside structures, i.e., not as loud, the subjects in the studies reported it as more annoying because of their response to visual and vibratory cues such as shaking of windows and the rattling of bric-a-brac on shelves and in cabinets. The effects of sonic boom on animals suggest that although there may be some startle effect, there appears to be little if any influence on their natural habitat. The studies on humans and animals were primarily conducted by the university teams with NASA only indirectly involved.

Maglieri, an on-site engineer on these projects (some were done at Indian Springs and Jackass Flats in Nevada and others in the Mojave desert in California), shared some vignettes from these projects: One incident took place at Jackass Flats and involved a 1500 ft. high tower that had been used many years ago for research regarding damage and exposure effects of atomic bombs. This tower was used in a sonic boom study to describe boom signatures at different heights above the ground. Microphones were attached at 100 ft. intervals to 1500 feet high and had to be checked or moved from time to time by the engineers and technicians. One particular day, two of the engineers had gone up on the small elevator that ran through the middle of this tower

when it lost electrical power due to Condors landing on the high tension wires some 60 miles away; the men were stranded at the top of the tower for several hours, and even though the tower had supporting guy cables, it still swayed precariously. Maglieri says that in another instance, at the Indian Springs, Nevada test site where the Strategic Air Command practiced over-the-shoulder "lobing" of a simulated nuclear bombing, a target marker was placed within a bulldozed circle of about two miles in diameter. There were numerous "dud" bombs stuck in the dry lake-bed inside the circle. Since there was some concern about any live bombs that might be in the area, Maglieri recalls asking a young airman the safest place on the site to which the airman replied, "right on the target; they never hit that."

Another vignette shared by Maglieri was that during the tests to determine if sonic booms had destructive potential, they ran tests to establish whether or not the very intense sonic booms from aircraft flying very close to the ground (100 times more intense than what we normally experience) could cause damage to structures and vehicles or could be used to clear land mine fields. Competition developed among the two groups of Air Force pilots as to which of them could fly the closest to the ground. Nominal altitudes of 300, 200, and 100 feet were specified. Each day the pilots would

fly lower and lower until the height of 50 feet was reached, which began to be disconcerting to those on the ground. One of these pilots who flew the 50-ft. pass was "Jack" Chennault, son of World War II fame, General Claire L. Chennault, who, as an ace pilot, formed the renowned group the Flying Tigers. Another famous pilot, Colonel Harrison Thyng, the second most decorated man in World War II after Audie Murphy, was an observer at these test flights.

A report issued in 1971 describes three of the projects Vera Huckel was involved in lasting a total of 170 days. The report notes that Huckel's office was "the central point from which all activity took place, and central point for all data." This same report also includes the comment "outstanding contribution" made by Brigadier General Edward B. Giller of the National Sonic Boom Evaluation Program. In addition Huckel later served as an advisor on several high level studies of sonic boom.

As a final note on sonic boom, Maglieri states that while interest in the effects of sonic boom waned in the early 1970s, it is once again taking on prominence because of the renewed interest in the development of a second generation

High Speed Civil Transport that now can fly at speeds of Mach 2.0 to 3.0 and also the National aerospace plane which can fly at hypersonic speed (Mach 5 to 7) and at higher altitudes. Maglieri was one of several engineers involved in the early sonic boom studies regarding each of these vehicles beginning in 1989 to determine the suitability of the existing, nearly 20 year old data base, and to assess the influence of the technology advances in aerodynamics, structures, propulsion, and avionics on their design and operation. Maglieri notes that the state of technology is such that aircraft may be designed so as to produce sonic booms that are much less objectionable than those currently being experienced: The sonic boom studies of the 1950s, 60s, and 70s established an initial database.

Vera Huckel's next major contribution following the sonic boom studies was as head of the computing Section at NASA after being promoted to Supervisory Mathematician. In this capacity, she reorganized the computing processes and organized what was called an "open shop" policy whereby an electronic computer was made available to programmers from other divisions: a policy that was soon recognized for its unique value to research. She was also noted for writing programs that reduced large volumes of data into more



correlational information. Huckel's computing techniques became standard throughout NASA-Langley Divisions. She describes her work in electronic computers as first starting with small operating manuals and having to write the programs that were needed for the type of research being done; she wrote the first program for the first electronic computer used at Langley.

Along with her other duties, Huckel was the author or co-author of numerous journal articles; she was sole author for three articles with the first written in 1948, second author for another 15 articles, and a contributor to an additional seven studies. The majority of these studies were on supersonics and sonic boom with her last article published in 1972.

## THE SPACE AGE AND ELECTRONIC COMPUTERS

There were two radical developments starting in the 1950s that greatly changed NACA/NASA and the work the human computers did. The first was the invention of the electronic computer and the second was the move into the Space Age. An excellent source for the history of the development of electronic computers is Paul Ceruzzi's *Beyond the Limits* (1989). He points out that the term "aerospace" was coined by the Air Force to establish the move into space flight (P.10), and that the evolution of the two technologies, space flight and electronic computers began to intertwine by 1945. He further notes that:

"The interaction of the two technologies has propelled each to evolve much faster than each could possibly have evolved separately...air and space would be impossible without computing...(and) computing would be far less advanced without aerospace (P.5).

Ceruzzi's descriptions of the limitations of the early electronic computers

one must build a different analog computer for every different type of problem to be solved... Compared to a desk calculator, this machine was

bulky and expensive...but it did not store programs internally...could carry out only short and inflexible sequences of arithmetic operations ...it came with almost no instructions or guides.

was experienced first-hand by the human computers who made the transition into electronic computers. Vivian Adair, who began working at LRC in 1943 and stayed until 1972, was one of the computers who made this transition from human computer to electronic computing. She describes her first job on the electronic computers as being similar to that of a telephone operator because it had a board with a terminal that fed into a slot in the IBM computer and one had to connect wires for the appropriate formulas to this board. Adair notes that her first electronic desk-computer was a Wang and that by the time she worked on the newer IBM electronic computer, it was sophisticated enough to be self-correcting. She comments that the advances were so rapid that in her last years at NASA (early 1970s), she was doing trigonometry programming.

Several of the human computers, Vera Huckel was one, report that in the early years of electronic computing, they had to write the programs that were needed for the research data they were working on because the electronic computers were not equipped with the programs appropriate for solving aeronautical problems.

New programs developed rapidly and the women had to learn to use them as quickly as possible. Dorothy Vaughan, another of the women to move into electronic computing, states she was able to learn the FORTRAN program fairly easily because it used algebraic language, but found later programs more difficult to learn. She further notes that the computers had to teach the engineers how to use FORTRAN. Kathryn Peddrew recalls that the key punch computer operation seemed so "high-tech" when it was first introduced. She says you had to key punch the data onto cards that were then fed into the computer. Peddrew also notes that "you had to know the kind of results the engineers were looking for in order to know which program to use".

Barbara Weigel transferred to the Electronic Computing Section in the 19-foot tunnel building in order to work with the IBM machines. She also recalls that programs had to be written for the unique research that was being done at NASA-Langley. Weigel agrees with Dorothy Vaughan that you had to take many classes in order to keep up with the rapidly developing electronic computers. Weigel describes programming as being similar to playing a game puzzle; it was a challenge to develop a fast, efficient, self-checking,

accurate program as quickly as possible. She further adds that some programs needed constant revision in order to meet unique research needs. To highlight the rapid advances in electronic computers, Weigel points out that by the end of her career (she retired in 1980), she was working in the Analysis and Computation Division doing graphics on the computer.

Concurring with the other women who moved into electronic computing, Mary Jackson states that they not only had to learn new computers and new programs, but also had to write training manuals for the electronic computers as well as make the transition into the new space research. Jackson qualified as an engineer in 1958 and attributes this promotion to two factors: first, she took the extension courses offered by the University of Virginia and taught at Langley by Langley engineers, and second, that her boss, Kasimir Carnecki, a senior scientist, encouraged and helped her to advance. Several of the human computers state that promotions and advancements often depended on this kind of help. An important avenue to advancement was to make contributions to written reports; however, this opportunity depended on which scientist one worked for. Jackson says she

was encouraged to run tests from start to end, to write reports, and to attend conferences. Emma Jean Landrum agrees with Jackson's assessment of the opportunities for advancement, also noting the importance of publishing articles. She recalls she was very pleased when she attended an American Institute of Aeronautics conference in 1980 and was told by a young scientist that he was using data she had collected in the 1960s for his research.

Jackson worked in boundary layers i.e., the layer of air referred to as "skin friction" surrounding an aircraft. Jackson notes that air flow can be reduced by roughness on surfaces or such small parts as the size of the rivets used. When aircraft speed is high enough, these sources of skin friction create serious drag. As noted earlier in the discussion of her work, Jackson's work involved being on a catwalk in the wind tunnel during tests in order to measure the effect of almost infinitesimal adjustments in rivet protrusions. It was this work that she feels caused her some hearing loss. Jackson concluded by stating how very proud she is of the fine work done by the human computers in the early days of electronic computing.

Betty Farmer, who was the last to arrive (1958-the year NACA officially became NASA) and the last to retire (1988),



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notes that Langley had just purchased an IBM computer with a two-tape drive, which was "the biggest thing in the world." She relates that in the early part of her career, it was not unusual to have to load as many as 20 large trays of key-punched cards into the computer. According to Farmer, it was often necessary to enlarge the computing room because the computers got larger and the number of trays of key-punched cards to store ballooned. She states the elearly electronic computers had only numerical keys, but the later ones had alpha as well as numeric values. She commented that when she first arrived and was being trained on electronic computers, she was told not to train with a particular woman (she could not recall the woman's name) because this woman only used two fingers on the keyboard, but was known as the fastest computer operator there. Perhaps Vivian Adair, who had had to be innovative because of her physical condition in order to cope with the demands of the calculator she first used, could best appreciate this woman's two-finger operating style. Farmer also spoke of the rapid development in computer capability, which she found challenging and exciting. She recalls that it was not too long before they had eight-drive computing machines. Farmer operated a system which recorded data directly from the tunnels. She states it

was not unusual to have five tunnels running data at the same time, and it was sometimes necessary to call the tunnels to have the engineers suspend their tests until the computer operators could reload with fresh tapes.

Not unlike the earlier days when the human computer supervisors taught the women, it was women who taught the trainees on the electronic computers as well. Also similar to the earlier days, the women all worked well together and were supportive of each other. The only male computer operator Betty Farmer recalls was one who only worked nights. One of the things she recalls of what were her early years was that everyone felt part of the team because the engineers themselves brought the data to the operators and that the computer operators frequently went to the tunnels to become more familiar with the data on which they were working. Farmer made the comment that in her last years at Langley there was still a sense of urgency: everything was needed as soon as possible.

Helen Johnson, who also was at Langley during the transition to electronic computers, elected to help write reports and do editing rather than make the change over to electronic

computers. The human computers continued to be valuable past the 1958 transition to electronic computers because the introduction of electronic computers was accomplished slowly, the computer operations tedious (programs still had to be written), the need to train people, and because data was sent to the main computer, there were further delays in obtaining research results. It is noteworthy that as NASA moved from human computing to the use of electronic computers, the women either moved into the new phase or were terminated by attrition; none were dismissed.

The human computers who stayed at Langley into the Space Age make some interesting comments about this phase of their work. Dorothy Vaughan, who worked for 28 years and whose last job was on the Scout project, notes that in those early years they concentrated on the war effort with little thought to what else they were doing and that she really did not plan to stay on after the war. She says that it was not until later that she began to feel they were on "the cutting edge of something very exciting." When Barbara Weigel worked on the Mercury project she knew it was "big and important." Although she did not stay on into the Space Age, Margaret Block talks about the excitement of working on the Matador missile project. Kathryn Peddrew felt they were on the

threshold of an exciting breakthrough, especially when the first seven astronauts trained at Langley. Vivian Adair agrees with Peddrew, noting that these first astronauts trained in a building across from hers. She makes the further statement that she feels everyone was more conscientious in the early years. She feels errors in flight today are due to carelessness more than was present during the early years. Betty Farmer reports that they were "glued to the television sets" during the space launchings because "you felt you played a part in that accomplishment. Everyone took pride in a successful and safe launching." She further offers that she no longer watches launches because she is not familiar with them nor sure what part she might have played in their development.

Fred Moore, Assistant Branch Chief of the Management Informations Systems Branch at NASA-Langley, was contacted and asked to provide information on the state-of-the-art of computers at that facility. He says that main frame computers are beginning to replace the wind tunnels for testing and super-computers now create the scale-models that were formerly done by hand. Moore reports that he was told (but has not confirmed) that the new Boeing 777 was designed on the computer with flight tests done on the first plane

built from the design, whereas in the past they would first build a prototype before building the plane to be tested in the air. He also states that because of the capabilities of the computers, they no longer need to worry about Reynolds number; what once took months can now be done in hours.

However, Moore does comment that in addition to feeding data directly into the main frame, they also use the "core system" wherein each Section is able to electronically compute their own work. It should be noted that this core system is not at all dissimilar to the human computers performing this operation in each Section.

Moore adds that this core system has led to what he refers to as a "hidden complex" i.e., because the electronic computers are supposed to be user-friendly, personnel are not always trained in their usage, especially newer programs. This results in them not knowing what to do if they run into problems on the computers. He feels computer technology continues to advance faster and be adopted sooner than people can be trained to use it. Using the example of the new voice-activated programs, Moore notes that if problems arise with it, it may not be easily discernable as

to whether the problem is with the machine or with the individual operating it.

It would seem that the outstanding difference between these core-system groups and the human computers is that the human computers arrived already trained (they were mathematicians); because aeronautics was pioneer work at the time, the human computers had more first-hand knowledge of the research being done. As Ceruzzi notes in the conclusion of his 1989 book:

As of this writing, the highest-flying, fastest airplane in the United States is still the SR-71, designed over twenty years ago by Clarence "Kelly" Johnson...For that and for all the other famous airplanes he designed, Johnson's primary computational tool was a ten-inch slide rule (P.223).

## AFTERWORD

All of the human computers in this study have remained active in their retirement years. Vivian Adair, with a background in conservatory training, became active in choral and bell choirs in her church after caring for her father for seven years. She enjoys traveling and claims that Paris is her favorite city. On one of my last visits to her home, she was preparing for her third Christmas time party. Rowena Becker has devoted many of her years to environmental problems. She organized a local American Association of University of Women (AAUW) environmental study that lasted for four years and served on a local wetlands board for an additional five years. Margaret Block is active in her church and enjoys playing tennis as often as she can. Marie Burcher worked as an historical interpreter for Colonial Williamsburg for 12 years and travels both here and abroad with her husband. Betty Farmer volunteers her time to her church and the local library. Vera Huckel continues to remain very active in her long term commitment to United Way Services, AAUW, and Soroptimist International. Mary Jackson gives her time to numerous church and local groups as well

as tutoring high school and college students in mathematics; she is especially proud of her activities that benefit children. Helen Johnson is active in her college alumni association and several other groups too numerous to list. Emma Jean Landrum devotes her time to the Daughters of the American Revolution (DAR) and other groups as well. Kathryn Peddrew says she is enjoying her retirement years doing handcrafts. Dorothy Vaughan works with the local YWCA and like to travel whenever she can get away. Barbara Weigel enjoys church work and exercising. Helen Willey remains active in the AAUW, her church, a local Fine Arts Guild and several local college Campus Ministries; she says her most favorite activity is taking her grandchildren on foreign trips.

The human computers share a sense of pride and accomplishment for their years at the Langley Research Center. Several of them meet one Thursday a month for lunch and many of them continue the friendships that began at Langley. In addition two NACA reunions have been held: the first in Ashville, North Carolina in 1976 with 625 in attendance, and the second attended by 702 at Williamsburg, Virginia, in 1982. The names of some of the other human computers is given in Appendix B.



An incident shared by Helen Willey best sums up the little recognition the human computers have been given. She ruefully noted that when she visited the new Space Center housing the history of NACA and NASA when it opened in Hampton, she overheard a woman say upon seeing a photograph of a woman included in the exhibit, "I doubt that she stayed very long".

## BIOGRAPHIES

### VIVIAN ADAIR

(current photograph)

Born September 9, 1916

Years at NACA/NASA 1943-1973

Since Retirement: Active in the Hampton Women's Club; Penguin Travel Club; First United Methodist Church (adult choir and choral handbell choir); volunteer for Hampton Senior Citizens' Club; and Delta Zeta Sorority.

Hobbies: travel, photography, woodworking, and music.

ROWENA BECKER

(current photograph)

Born October 5, 1921

Years at NACA 1942-1947

Since Retirement: Member of the Newport News Wetlands Board; Committee for Social Concerns; First United Methodist Church; and the Salvation Army's "Habitat for Humanity".

Hobbies: Trips to foreign countries, gardening, and plant experimentation.

MARGARET BLOCK

(current photograph)

Born December 12, 1929

Years at NACA/NASA 1951-1956

Since Retirement: Active in Hidenwood Presbyterian Church.

Hobbies: tennis and her grandchildren.

MARIE BURCHER

(current photograph)

Born March 6, 1921

Years at NACA 1942-1949

Since Retirement: Historical Interpreter at Colonial  
Williamsburg; Grace Episcopal Church, Yorktown.

Hobbies: Traveling with her husband throughout the United  
States and visiting foreign countries.

BETTY FARMER

(current photograph)

Born September 30, 1922

Years at NASA 1958-1988

Since Retirement: Active church Deacon; member of the  
Hampton Library Gift Shop.

Hobbies: Walking, exercise classes, travel, and art.

VERA HUCKEL

(current photograph)

Born April 18, 1908

Years at NACA/NASA 1939-1972

Since Retirement: United Way Budget Chair; American Association of University Women (AAUW); and Soroptimist International.

Hobbies: none

MARY JACKSON

(current photograph)

Born April 9, 1921

Years at NACA/NASA 1950-1985

Since Retirement: Continental Societies, Inc.; King Street Community Center; Boys Club of Hampton; Peninsula Association of Retarded Citizens; Girls Scouts of America; National Technological Association; Bethel African Methodist Episcopal Church; and tutoring high school and college students in mathematics.

Hobbies: sewing and crafts.



HELEN JOHNSON

(current photograph)

Born August 16, 1906

Years at NACA/NASA 1942-1976

Since Retirement: College Alumni Association; Hampton Historical Society; Chair, Peninsula Mental Health Association; and Franklin Baptist Church.

Hobbies: Bridge, knitting, and researching family history.

EMMA JEAN LANDRUM

(current photograph)

Born January 24, 1926

Years at NACA/NASA 1946-1978

Since Retirement: Active in Macon County, North Carolina Historical Society; Daughters of the American Revolution (DAR); and First United Methodist Church.

Hobbies: travel and family history research.

KATHRYN PEDDREW

(current photograph)

Born June 14, 1922

Years at NACA/NASA 1943-1986

Since Retirement:

Hobbies: crafts.

DOROTHY VAUGHAN

(photograph not available)

Born October 20, 1910

Years at NACA/NASA 1943-1971

Since Retirement: Active in Peninsula Y.W.C.A. and the Silver Belles Club.

Hobbies: travel, crossword puzzles, and music.

BARBARA WEIGEL

(current photograph)

Born July 23, 1921

Years at NACA/NASA 1944-1980

Since Retirement:

Hobbies: Reading, exercise, baking, and church work.

HELEN WILLEY

(current photograph)

Born June 18, 1911

Years at NACA/NASA 1941-1973

Since Retirement: American Association of University Women (AAUW); United Methodist Church; Campus Ministries; Women's Club of Hilton Village; and Homemakers Club.

Hobbies: Family, travel, crafts, and collecting antiques.

## AERONAUTICAL ENGINEERS

RALPH BIELAT - Graduated from Rensselaer Polytechnic Institute in 1941 with a degree in Aeronautical Engineering. He arrived at NACA in 1941 and was named Assistant Head of the Transonic Aerodynamics Branch in 1963. Except for an interruption of a few years at United Aircraft in Connecticut, he retired from NACA/NASA in 1980 having worked for 39 years.

HARVEY HUBBARD - Graduated from the University of Vermont in 1942 with a degree in Electrical Engineering. He began to work for NACA in 1945, two years before he was separated from the Air Force following World War II. He retired in 1980 after almost 35 years. He is the editor of the two volume book, *Aeroacoustics of Flight Vehicles: Theory and Practice*, published in 1991.

DOMENIC MAGLIERI - Graduated from the University of Pittsburgh in 1951 with a degree in Mechanical Engineering with an option in Aerodynamics. He began his career at NACA in 1951 and was involved in aircraft noise and sonic boom activities, serving as Chief of the Noise Control Branch and Manager of Subsonic/Supersonic Transport Technology until his retirement in 1986. Currently, he is Director for Projects at Eagle Engineering in Hampton, Virginia, where he is responsible for all the aircraft noise and sonic boom work. He is the author of more than 150 technical publications.

AXEL MATTSON - Graduated from North Carolina State College in 1940 with a degree in Mechanical Engineering with an Aeronautical option. He arrived at NACA in 1941 becoming Section Head of the 8-foot tunnel in 1948. After a 34 year career in high speed flight research and manned space flight, he retired in 1975 as Assistant Director of External Affairs.

## APPENDIX A.

NACA Personnel files were lost or destroyed. The additional names of human computers given here were provided by the people who worked at NACA with them.

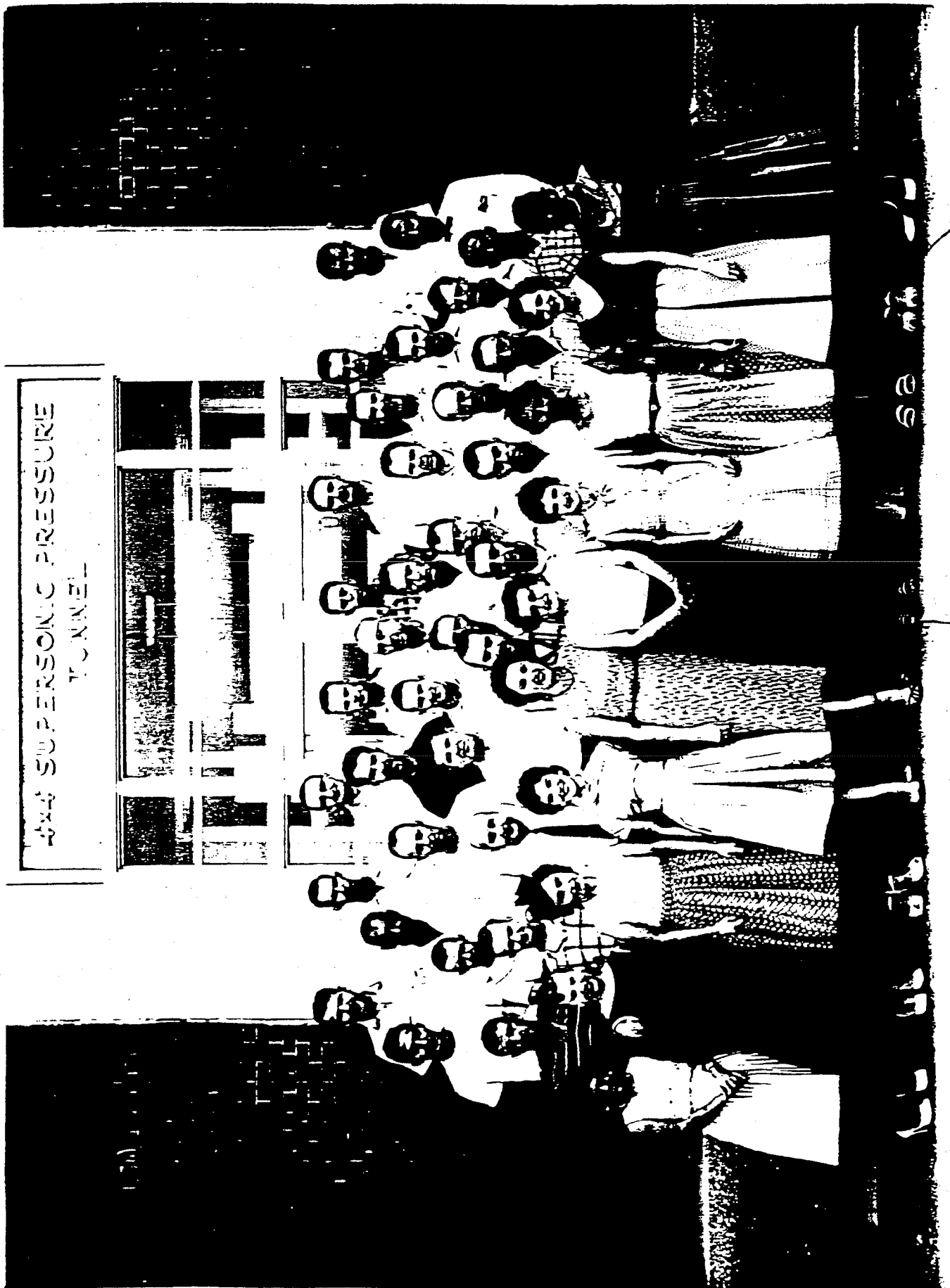
Lillian Bailey  
Doris Barron  
Freida Block  
Pat Boyd  
Sarah Bullock  
Gloria Champagne  
Peg Clelland  
Nancy Colter  
Roslyn Cordwell  
Doris Crumpler  
Ruby Davis  
Georgia Dees  
Ferne Driver  
Barbara Durling  
Marie Eichmeier  
Lynn Fleming  
Dorothy Garmon  
Edna Goodall  
Phyllis Hieser  
Sarah Huckster  
Leslie Hunter  
Laura Jackson  
Maryann Johnson  
Nan Jones  
Kitty O'Brien Joyner  
Maxine Justice  
Mary Kaylor  
Julia Lancaster  
Kathleen Land

Nancy Maddox  
Isabelle Mann  
Gladys Martz  
Anne Mattson  
Ann Mennell  
Betty Millard  
Dot Mills  
Juanita Parker  
Connie Pegues  
Cot Phillips  
Viola Phillips  
Jean Ruddie  
Willie Ruffin  
Amy Ruhlin  
Amy Sabol  
Penny Malone Samples  
Jean Scott  
Shirley Shelton  
Eunice Gray Smith  
Jeanne Smith  
Betty Stafford  
Penny Stokes  
Betty Toll  
Jena Tucker  
Catherine Turner  
Kitty Weston  
Millie Woodling  
Irene Young  
Kathy Young



**APPENDIX B.**

**ADDITIONAL PHOTOGRAPHS OF HUMAN COMPUTERS**









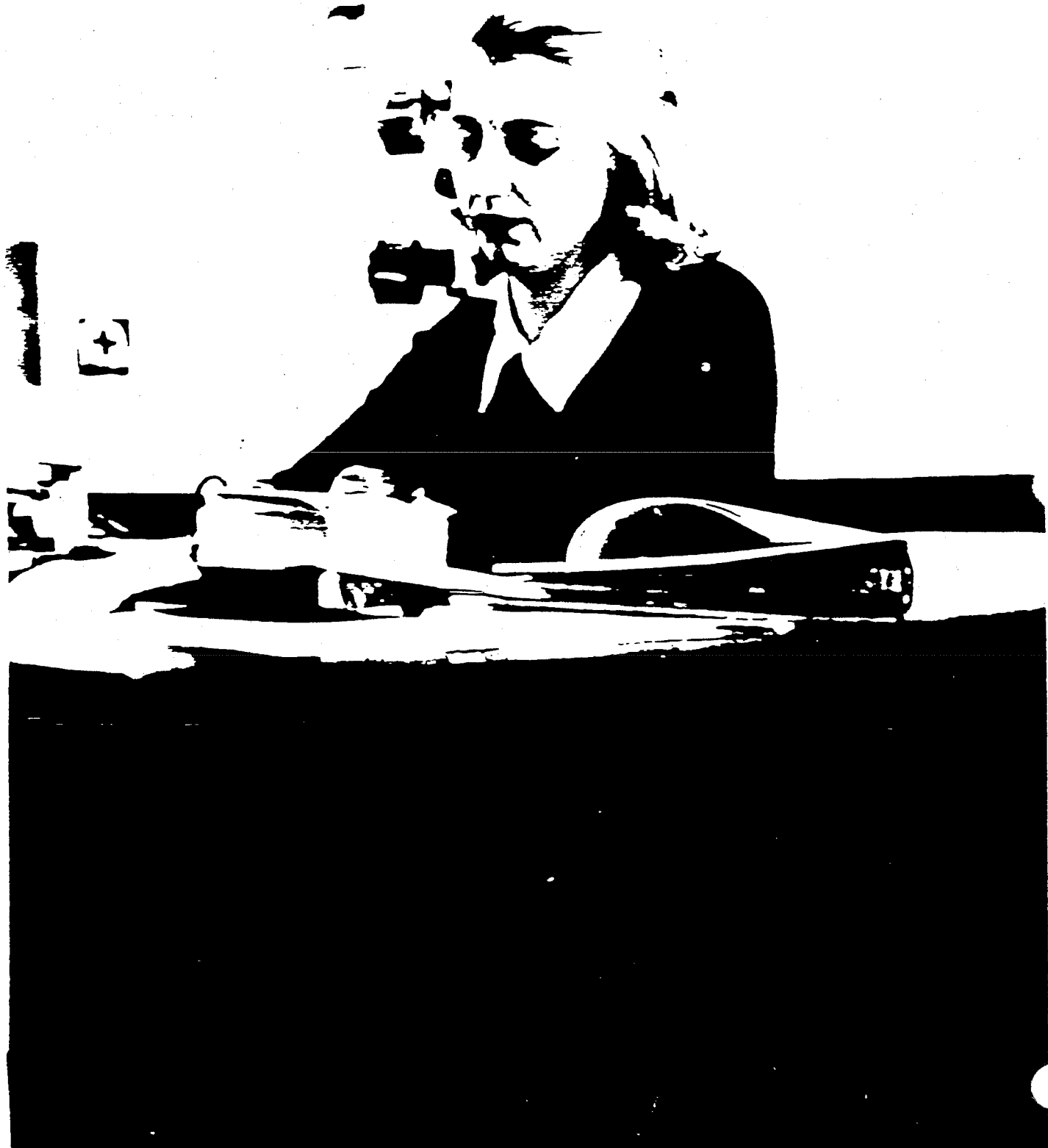
















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